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A CO-OPERATIVE STUDY OF THE UTILITY OF DIFFERENT METHODS FOR EVALUATING FLOUR STRENGTH

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Introduction

For the purpose of evaluating flours on the basis of strength, cereal chemists have evolved various baking procedures which are presumed to indicate the baking properties of a flour with a reasonable degree of accuracy. In an effort to standardize test baking, the American Association of Cereal Chemists has developed and adopted a basic test which, in combination with certain supplementary procedures, is designed to reveal the particular baking characteristics of a series of flours.

The value of the A. A. C. C. baking test has been recently subjected to criticism by Kent-Jones (1934), who, after applying the basic and certain supplementary procedures in his own laboratory, concluded that the basic test does not give proper guidance in distinguishing flours of the type normally milled in Europe, and because of this, faulty conclusions are likely to result. In place of such a test, in which the volume of the finished loaf is generally taken as the index of baking strength, Kent-Jones advocates employing different baking methods for different flours and judging the behaviour of the fermented dough rather than the final loaf, since he believes that the strongest flours do not always give the largest loaves.

Kent-Jones further advocates that, if standard procedures are desirable, the best method to get reliable results by all chemists might be the adoption of standard dough-testing instruments. The best baking tests are unable to differentiate sharply the extent of the various physical factors which influence dough quality.

In commenting on Kent-Jones' criticism, Blish (1934), and Geddes, Larmour and Mangels (1934), state that Kent-Jones has apparently

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misunderstood the fundamental philosophy underlying the A. A. C. C. experimental baking test and point out that American cereal chemists regard the basic test as merely a point of reference and that it is intended to be used in conjunction with supplementary procedures. It is the data obtained from a group of tests including the basic, rather than the basic alone, which are considered to give the desired information.

In view of Kent-Jones' criticism of the utility of the A. A. C. C. baking test and other test baking procedures in which the final loaf, rather than the character of the fermenting dough, is taken as the criterion of strength, it seemed of interest to undertake a co-operative study in which both types of methods would be applied to the same series of flours.

The authors, therefore, agreed to exchange a set of flour samples under key numbers, each investigator being requested to classify the flours in both sets in order of descending quality, based on the results of tests conducted in his own laboratory according to his particular methods of analysis. Each author was presumed to know the evaluation of his own set of samples, based on knowledge of the flours and of the wheats employed. In addition to employing the methods he advocates, Kent-Jones undertook to apply the standard A. A. C. C. baking test and one of the supplementary procedures recommended by Geddes, namely, the malt-phosphate-bromate formula.

By this arrangement each investigator was supplied with one set of flour samples of varying strengths of which he was in complete ignorance regarding their composition; while, on the other hand he retained a similar series of flours of known origin and composition. By classifying both sets of samples on the basis of strength according to the methods of testing favoured by each investigator, it would be possible, by referring to the classification as indicated by the character and the composition of the various flours, to determine which type of testing procedure would be the most dependable for the purpose.

In presenting the results obtained, it has been deemed advisable for each author to prepare separate reports which, in turn, would be exchanged and a separate discussion on the results of the findings prepared by each author.

Experimental Material

For the purpose of this study, eleven flours were submitted by the Dominion Grain Research Laboratory, and fourteen by Kent-Jones. These are listed in Table I in an *a priori* order of strength based on a knowledge of their nature and composition. The samples forwarded by the Winnipeg laboratory were all untreated, experimentally milled

straight grade flours, corresponding in extraction to a 95% commercial patent. The different wheats employed were milled separately and, where blends were supplied, the component flours were thoroughly mixed in a McLellan mixer. The flours and blends were selected so as to provide a series varying widely in strength, protein content and protein quality, so that the *a priori* classification could be easily and accurately decided upon.

The Dover samples were carefully collected so as to be representative of the range of flour strength with which the cereal chemist in Great Britain has to deal. Full information concerning the blends, treatment, etc., was obtained and this, combined with a knowledge

TABLE I

LIST AND DESCRIPTION OF SAMPLES ARRANGED IN THEIR PRESUMED ORDER OF BAKING STRENGTH

Flour sample number	Description of experimental material	Remarks
	Samples supplied by the Dominion Grain Research Laboratory	
1	95% untreated patent flour, experimentally milled from 100% high protein No. 1 Manitoba Northern wheat.	An exceedingly strong flour of exceptionally high protein content and quality.
2	95% untreated patent flour, experimentally milled from 100% average No. 1 Manitoba Northern.	A strong flour; similar to flour No. 1 but of lower protein content and baking strength.
8	A blend of 50% high protein No. 1 Manitoba Northern (flour No. 1) and 50% English Yeoman (flour No. 5).	A strong flour; considered to be equal in baking strength to flour No. 2.
9	A blend of 50% high protein No. 1 Manitoba Northern (flour No. 1) and 50% French.	A strong flour of slightly lower strength than flour No. 8.
10	A blend of 35% high protein No. 1 Manitoba Northern (flour No. 1) and 65% French.	A medium-strength flour.
3	95% untreated patent flour, experimentally milled from 100% low protein No. 1 Manitoba Northern.	A medium-strength flour, of decidedly lower protein content and baking strength than is usual from this grade.
11	A blend of 20% high protein No. 1 Manitoba Northern (flour No. 1) and 80% French.	A medium-strength flour considered almost equal to flour No. 3.
7	A blend of 27.6% Average No. 1 Manitoba Northern (flour No. 2) and 72.4% French.	—
6	A blend of 14.5% high protein No. 1 Manitoba Northern (flour No. 1) and 85.5% French.	—
5	95% untreated patent flour, experimentally milled from 100% English Yeoman.	A low strength flour, but superior to the usual run of that from ordinary Red English wheat.
4	95% untreated patent flour, experimentally milled from 100% Australian wheat.	A weak flour, typical in strength of that from the usual run of Australian export wheat.

TABLE I—(*Continued*)

Flour sample number	Description of experimental material	Remarks
	Samples supplied by Kent-Jones	
Z1/401	Milled from 100% No. 1 Manitoba. Treated with Agene and Bromate.	Very strong flour, used for 20-hour sponges in Scotland.
Z1/417	Milled from 50% No. 1 and 50% No. 4 Manitoba. Bromate treated and bleached with NO_2. Also received slight heat-treatment.	A strong flour, stronger than usual for ordinary baking processes.
Z1/416	Milled from 100% No. 4 Manitoba. Electric (NO_2) bleach and slight heat-treatment.	A strong flour, stronger than usual for ordinary baking processes.
Z1/403	Blend: 25% No. 1 Manitoba; 12½% No. 5 Manitoba; 12½% good Plate: 25% good Russian; 25% Hungarian. Agene treated.	A strong commercial flour but not as strong as the above samples.
Z1/400	Blend: 19% Nos. 1 and 2 Manitoba; 18% Nos. 4 and 5 Manitoba; 18% Plate and Russian; 30% Hungarian, Moroccan and Australian; 15% weak German. Agene treated.	Strong patent grade commercial flour.
Z1/399	Blend: same wheat blend as Z1/400 but straight run flour.	
Z1/415	Blend: 25% No. 1 Manitoba; 25% No. 5 Manitoba; 30% mild Russian; 25% weak German. Treated heat-treatment and bromate. Bleached electric bleach (NO_2).	All commercial flours. These samples are very similar in strength and it is difficult to place them in a definite order.
Z1/404	Blend: 30% Nos. 1 and 2 Manitoba; 15% No. 5 Manitoba; 25% Plate and mild Russian; 25% Hungarian; 5% German. Agene treated.	
Z1/396	Milled from 100% good strength Plate wheat. Agene treated.	These samples are rather similar and it is difficult to place them in a definite order.
Z1/418	Milled from 100% medium strength Russian wheat. Heat treatment.	
Z1/397	A mixture of 50% of the medium-strength Z1/415 and 50% weak English.	
Z1/414	Milled from 100% Yeoman wheat. Unbleached and untreated.	Stronger than ordinary English but not as strong as above blends.
Z1/398	Weak English wheat. Agene treated.	—
Z1/402	Weak French wheat. Unbleached and untreated.	—

of the districts in which some of the flours were competing, enabled them to be placed in the *a priori* order of strength indicated in Table I.

Experimental

Studies Conducted in the Dominion Grain Research Laboratory

Miscellaneous Determinations

As an aid in the interpretation of the baking tests, the flours were submitted to protein, ash and diastatic activity determinations. Nitrogen was determined by the Kjeldahl-Gunning-Arnold procedure, ash by the standard A. A. C. C. procedure, and diastatic activity by

the method recently proposed by Blish and Sandstedt (1933). The results, expressed on a 13.5% moisture basis, are given in Table II.

TABLE II

RESULTS OF PROTEIN, ASH AND DIASTATIC ACTIVITY DETERMINATIONS

Flour sample number	13.5% moisture basis		
	Protein (N×5.7)	Ash	Diastatic activity
	%	%	(*mg. maltose per 10 g. flour*)
Samples supplied by the Dominion Grain Research Laboratory			
D.G.R. 1	14.7	0.43	104
2	12.4	0.44	100
8	12.5	0.44	150
9	11.9	0.40	98
10	11.1	0.41	90
3	10.2	0.50	126
11	10.4	0.38	90
7	10.2	0.42	100
6	10.1	0.39	90
5	9.7	0.42	188
4	9.1	0.41	90
Samples supplied by Kent-Jones			
Z1/401	13.7	0.49	142
417	12.1	0.47	166
416	11.9	0.48	172
403	10.6	0.38	150
400	10.7	0.39	156
399	11.4	0.50	152
415	11.2	0.45	218
404	10.6	0.40	152
396	9.2	0.44	110
418	10.2	0.48	142
397	9.8	0.44	78
414	9.3	0.44	152
398	7.3	0.44	98
402	7.8	0.43	98

Experimental Baking Methods

Since the primary object of this investigation is to determine the relative value of different methods for evaluating flours, it seemed advisable to apply a large number of baking procedures, many of which in the writer's (Geddes) experience have not proven satisfactory for flours experimentally milled from Canadian hard red spring wheats, but which might conceivably be of considerable value in the instance of samples commercially milled from wheats of unknown origin. In addition, the samples available offered an excellent opportunity to apply baking methods which had not been previously employed in this laboratory. In all, nineteen variations in formula or procedure were employed as outlined below. Unless otherwise specified, the

technique employed was that outlined by Geddes (1934) as the "Standard Procedure" of the Official A. A. C. C. Basic Baking Test, the Hobart mixer equipped with two dough hooks and low-form baking pans being used.

Standard Procedure with Varying Formulas

Method No. 1—Basic formula.
Method No. 2—Malt-phosphate formula—Basic formula plus 0.3% diastatic malt (approx. 200° Lintner) and 0.1% $NH_4H_2PO_4$.
Method No. 3—Bromate formula—Basic formula plus 0.001% $KBrO_3$.
Method No. 4—Malt-phosphate-bromate formula—Basic formula plus 0.3% diastatic malt (approx. 200° Lintner), 0.1% $NH_4H_2PO_4$ and 0.001% $KBrO_3$.
Method No. 5—High yeast-sugar formula—Basic formula except that 5% yeast and 6% sucrose are used. (Larmour and Brockington, 1934.)
Method No. 6—High yeast-sugar bromate formula—Method No. 5 with the addition of 0.001% $KBrO_3$. (Larmour and Brockington, 1934.)

Fixed Formula with Varying Fermentation Times

(Formula—malt-phosphate (No. 2), excepting that 1% yeast is used)

Method No. 7	2	hours' fermentation
Method No. 8	3	" "
Method No. 9	4	" "
Method No. 10	5	" "
Method No. 11	6	" "
Method No. 12	7	" "

Procedures involving Variable Formulas and Mixing Times
Hobart-Swanson Mixer

Method No. 13—Malt-phosphate formula (No. 2)—Dough mixed 1 minute in Hobart-Swanson mixer.
Method No. 14—Malt-phosphate formula (No. 2)—Dough mixed 3 minutes in Hobart-Swanson mixer.
Method No. 15—Malt-phosphate formula (No. 2)—Dough mixed 6 minutes in Hobart-Swanson mixer.
Method No. 16—Malt-phosphate-bromate formula (No. 4)—Dough mixed 1 minute in Hobart-Swanson mixer.
Method No. 17—Malt-phosphate-bromate formula (No. 4)—Dough mixed 3 minutes in Hobart-Swanson mixer.
Method No. 18—Malt-phosphate-bromate formula (No. 4)—Dough mixed 6 minutes in Hobart-Swanson mixer.

Short Fermentation Iodate Method

Method No. 19—Basic formula plus 0.0005% KIO_3, with 1½ hours' fermentation (Sandstedt and Blish, 1933).

Baking Results

While it is realized that certain loaf characteristics other than volume are of importance in evaluating flour strength, for the sake of simplicity the mean loaf volume data only are given in Table III for the different baking methods. Volume is the only loaf characteristic which is capable of definite quantitative measurement and expression, and, in the light of previous experience, it is believed to satisfactorily reflect relative baking strength if suitable baking procedures are employed.

As previously noted, the Dover samples were baked without any knowledge of their classification, but after forwarding our data to England, the *a priori* order of strength was received from Kent-Jones and, in order to study the flours on this basis, the loaf volume data on both sets of samples respectively have been arranged in order of decreasing strength on the *a priori* basis. A cursory examination of Table III reveals that not only is there a wide variation between methods in the relative placing of the different flours, but also in the spreads between the largest and smallest loaf volumes for any one baking procedure.

In order to arrive at a classification of the flours for each baking procedure, differences between any two mean loaf volumes of 30 cc. were regarded as significant. This figure was arbitrarily selected on the basis of the studies conducted by Geddes, Goulden, Hadley and Bergsteinsson (1931), who concluded, on the basis of studies of the variability in loaf volume between replicate bakings that the differences between the means for duplicate bakings of any two flours should be 28 cc. or greater to be significant when the standard deviation of replicate bakings of each flour is 14 cc., which is of the order found for the difference between duplicates in the present series. In grouping the flours, classes were set up for each series and baking method, using class intervals of 30 cc., and the flours allocated to the particular class into which they fell. These classes were numbered serially, commencing with the one of largest volume, the serial numbers thus obtained indicating the arrangement in order of decreasing strength. The classifications of the two series of flours by this means for each baking method are shown in Table IV.

There is a very marked variation in the relative placings of the flours, also in the number of groups into which they fell for the different baking methods. In certain methods, notably 7 and 8, the loaf volume range between the samples of extreme strength is so narrow that, allowing 30 cc. as a significant difference, the flours are classified into only a few groups.

Aitken and Geddes (1934) found that the tolerance of a flour to severe baking conditions, such as the use of progressively increasing dosages of potassium bromate, extended fermentation, prolonged mixing time, and progressive dilution with weak flour, was valueless as an index of strength, since the strongest flours studied were more sensitive to the changes in baking conditions imposed. Since the loaf volumes of the stronger flours were reduced to a greater extent than those which were weaker, the differentiation in loaf volume was decreased, thus rendering such methods unsuitable for classifying the flours on the basis of actual loaf volume. Similar observations were

TABLE III

MEAN LOAF VOLUME DATA BY VARIOUS BAKING PROCEDURES

Flour sample number	Standard procedure with varying formulas						Malt-phosphate low yeast formula with varying fermentation times						Malt-phosphate formula with different mixing times (Hobart-Swanson mixer)			Malt-phosphate-bromate formula with different mixing times (Hobart-Swanson mixer)			Short fermentation iodate method No. 19
	Basic formula No. 1	Malt-phosphate formula No. 2	Bromate formula No. 3	Malt-phosphate-bromate formula No. 4	High yeast-sugar formula No. 5	High yeast-sugar bromate formula No. 6	2 hr. No. 7	3 hr. No. 8	4 hr. No. 9	5 hr. No. 10	6 hr. No. 11	7 hr. No. 12	1 min. No. 13	3 min. No. 14	6 min. No. 15	1 min. No. 16	3 min. No. 17	6 min. No. 18	
	Cc.	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*
Samples supplied by the Dominion Grain Research Laboratory																			
1	655	710	765	935	788	908	535	625	660	660	635	540	860	940	755	960	1005	718	660
2	518	610	648	765	675	758	510	590	600	585	530	505	680	760	580	800	800	655	572
8	592	680	682	760	695	685	535	595	670	640	600	555	735	800	610	740	720	535	600
9	545	622	620	695	660	665	530	580	610	570	520	420	645	660	560	770	698	552	578
10	512	565	585	615	608	605	525	540	585	545	495	410	600	610	505	660	600	490	552
3	475	545	532	550	572	520	515	540	540	560	540	515	580	600	515	590	605	480	502
11	495	528	552	542	580	565	495	540	560	535	495	400	560	550	440	580	570	460	558
7	490	568	550	568	578	565	510	540	570	530	495	400	600	585	490	630	565	480	542
6	505	505	530	538	570	538	495	535	560	540	430	395	550	525	440	550	510	420	568
5	560	608	535	570	585	528	505	550	560	590	530	510	630	570	470	595	530	440	550
4	480	515	500	532	530	472	490	535	535	500	480	435	550	540	440	540	505	440	552
Range	180	205	265	403	258	436	45	90	135	160	205	160	310	415	315	420	500	298	158

TABLE III—(*Continued*)

Flour sample number	Standard procedure with varying formulas						Malt-phosphate low yeast formula with varying fermentation times						Malt-phosphate formula with different mixing times (Hobart-Swanson mixer)			Malt-phosphate-bromate formula with different mixing times (Hobart-Swanson mixer)			Short fermentation iodate method No. 19
	Basic formula No. 1	Malt-phosphate formula No. 2	Bromate formula No. 3	Malt-phosphate-bromate formula No. 4	High yeast-sugar formula No. 5	High yeast-sugar bromate formula No. 6	2 hr. No. 7	3 hr. No. 8	4 hr. No. 9	5 hr. No. 10	6 hr. No. 11	7 hr. No. 12	1 min. No. 13	3 min. No. 14	6 min. No. 15	1 min. No. 16	3 min. No. 17	6 min. No. 18	
	Cc.	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*	*Cc.*
Samples supplied by Kent-Jones																			
Z1/401	658	715	665	665	718	655	565	620	690	705	575	560	800	900	550	760	810	555	635
417	575	632	560	548	620	515	540	570	600	590	590	540	700	745	505	650	700	475	560
416	570	640	585	568	660	580	530	590	625	625	630	590	740	765	500	710	690	485	575
403	515	565	478	488	595	520	530	565	615	545	510	510	590	660	535	540	590	500	442
400	555	588	502	510	575	492	545	605	610	580	525	490	615	600	500	565	570	480	495
399	500	560	490	485	600	515	550	610	610	580	560	510	650	635	480	570	620	480	505
415	565	615	525	518	590	510	540	590	635	590	540	520	690	725	530	620	640	520	562
404	525	582	492	530	595	505	530	555	590	575	530	535	650	695	510	575	605	505	470
396	460	468	430	435	468	438	520	545	515	495	475	465	505	495	410	460	480	440	392
418	520	612	570	630	605	600	510	535	565	570	530	545	670	695	630	685	695	605	540
397	538	605	530	552	565	502	530	565	600	570	540	520	630	600	520	585	580	490	542
414	475	520	490	502	558	500	490	560	575	550	535	490	620	585	450	590	530	465	495
398	430	420	385	395	415	420	450	470	460	430	430	420	430	415	395	415	395	400	358
402	470	512	482	495	522	480	470	510	520	510	490	380	540	510	410	515	490	410	500
Range	228	295	280	270	303	235	115	150	230	275	200	210	370	485	235	345	415	205	277
Maximum range	228	295	380	540	373	488	115	155	230	275	205	210	430	525	360	545	610	318	302

TABLE IV

SERIAL NUMBER OF GROUPS [1] INTO WHICH FLOURS ARE CLASSIFIED ON THE BASIS OF LOAF VOLUME OBTAINED BY THE DIFFERENT BAKING PROCEDURES

Flour sample number	Baking method number																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	Samples supplied by the Dominion Grain Research Laboratory																		
1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1
2	4	3	3	2	3	2	2	2	2	3	3	3	3	3	3	2	2	2	3
8	2	2	2	2	2	3	1	2	1	2	2	1	2	2	2	4	3	4	2
9	3	3	4	3	3	4	1	2	2	3	4	5	4	4	4	3	4	3	3
10	4	5	5	4	4	5	1	3	3	4	4	5	6	4	5	5	5	5	4
3	5	5	6	6	5	8	2	3	4	4	3	3	7	4	5	7	5	6	5
11	5	6	6	6	5	6	2	3	4	4	4	5	7	6	7	7	6	6	4
7	5	4	6	5	5	6	2	3	3	5	4	5	6	5	6	6	7	6	4
6	5	6	7	6	5	7	2	3	4	4	6	5	7	6	7	8	8	7	3
5	3	3	6	5	5	8	2	3	4	3	3	3	5	5	7	7	8	7	4
4	5	6	7	6	6	9	2	3	4	5	5	4	7	6	7	8	8	7	5
	Samples supplied by Kent-Jones																		
Z1/401	1	1	1	1	1	1	1	1	1	1	3	2	1	1	2	1	1	2	1
417	2	2	3	3	3	3	2	2	3	3	2	2	3	3	4	4	2	4	3
416	2	2	2	3	2	2	2	2	2	2	1	1	2	2	4	2	3	4	2
403	4	5	5	5	4	3	2	2	2	5	5	3	6	5	3	7	6	3	6
400	2	4	5	5	4	4	1	1	3	4	4	4	5	7	4	7	7	4	4
399	4	5	5	6	3	3	1	1	3	4	3	3	4	6	5	6	5	4	4
415	2	3	4	4	4	4	2	2	2	3	4	3	3	3	3	5	4	3	3
404	3	4	5	4	4	4	2	3	3	4	4	2	4	4	4	6	6	3	5
396	6	7	6	7	7	6	2	3	5	6	6	5	8	10	7	9	10	5	7
418	4	3	2	2	3	2	3	3	4	4	4	2	4	4	1	3	3	1	3
397	3	3	4	3	5	4	2	2	3	4	4	3	5	7	3	6	6	4	3
414	5	6	5	5	5	4	3	3	4	5	4	4	5	8	6	6	8	4	4
398	6	8	7	8	8	6	4	5	6	7	7	7	9	11	7	10	11	6	8
402	5	6	5	5	6	5	4	4	5	6	6	8	7	9	7	8	9	6	4

[1] The groups are numbered serially in order of decreasing strength, on the basis of 30 cc. being regarded as a significant difference between any two mean loaf volumes.

made by Larmour and Brockington (1934). These conclusions appear to be confirmed in the present study, since in both series prolonged fermentation and mixing of the doughs give a smaller differentiation than the less severe application of these conditions. It is of interest to note that the basic formula gives a relatively poorer differentiation of the flours in the series supplied by Winnipeg than in the instance of those received from Kent-Jones; this is in line with the results of previous investigations, such as those reported by Geddes and Larmour (1933), which indicate that oxidizing agents are essential ingredients

of baking formulas when testing unaged and unbleached experimentally milled flours.

At the outset it was realized from previous studies that the majority of the methods used were of little value for classifying experimentally milled flours, but it was felt that they might be of considerable utility in the instance of commercially milled flours such as were supplied by Kent-Jones, many of which might possibly have been both bleached and matured. When the tests were conducted however, the nature of the English milled flours was unknown and it seemed necessary to classify the flours in both sets of samples on the basis of the results by methods which are used by various Canadian laboratories and which have been found to give satisfactory differentiation in flour strength. On these grounds, the methods selected for the purpose of arriving at a final classification were: malt-phosphate-bromate (No. 4); high yeast-sugar bromate (No. 6); malt-phosphate one- and three-minute Hobart-Swanson mix (Nos. 13 and 14), and malt-phosphate-bromate one- and three-minute Hobart-Swanson mix (Nos. 16 and 17). In these methods, either diastatic malt or a large percentage of sugar has been included in the formula and the relative loaf volumes may be regarded as an index of strength, independent of variations in the gassing power of the flours.

The mean loaf volumes by these six methods for each series of flours were averaged and the resulting values reclassified into groups on the basis of 11 cc. as a significant difference. This figure, like that of the 30 cc. value previously referred to, was arrived at on the basis of a standard deviation of 14 cc. between duplicate bakings. Since the final mean loaf volume obtained by averaging the results by the six methods selected comprises 12 loaves, the standard error for the mean of any one flour is $14/\sqrt{12}$ while the standard error of the difference between the means for any two flours would be $14/\sqrt{12} \times \sqrt{2}$ or 5.4. In order to be reasonably certain that any two flours actually differ in mean loaf volume, this implies that the difference between the mean values for any two flours must be 10.8 cc. or greater, *i.e.*, approximately 11 cc. The classes into which the various flours fell were numbered serially, as already described for the classification on the basis of individual baking methods.

The mean loaf volumes and the final classification based thereon are given in Table V in comparison with the *a priori* arrangement.

TABLE V

COMPARISON OF FINAL WITH *a priori* CLASSIFICATION OF FLOURS IN ORDER OF DECREASING BAKING STRENGTH ON THE BASIS OF THE MEAN LOAF VOLUMES FOR THE SIX SELECTED METHODS [1]

Flour sample number		Nature of flour	Mean loaf volume
Classification			
Found	*a priori*		
		Samples supplied by the Dominion Grain Research Laboratory	
		Milled from	*Cc.*
1	1	100% high protein 1 Nor.	935
2	2	100% average 1 Nor.	760
8	8	50% high protein 1 Nor. plus 50% English Yeoman	740
9	9	50% high protein 1 Nor. plus 50% French	689
10	10	35% high protein 1 Nor. plus 65% French	615
7	3	100% low protein 1 Nor.	574
5	11	20% high protein 1 Nor. plus 80% French	561
3	7	27.6% average 1 Nor. plus 72.4% French	585
11	6	14.5% high protein 1 Nor. plus 85.5% French	535
6	5	100% English Yeoman	570
4	4	100% Australian	523
		Samples supplied by Kent-Jones	
401	401	Milled from 100% No. 1 Manitoba. Treated with Agene and Bromate.	765
416	417	Milled from 50% No. 1 and 50% No. 4 Manitoba. Bromate treated and bleached with NO_2. Also received slight heat-treatment.	643
418	416	Milled from 100% No. 4 Manitoba. Electric (NO_2) bleach and slight heat-treatment.	675
417	403	Blend: 25% No. 1 Manitoba; 12½% No. 5 Manitoba; 12½% good Plate; 25% good Russian; 25% Hungarian. Agene treated.	565
415	400	Blend: 19% Nos. 1 and 2 Manitoba; 18% Nos. 4 and 5 Manitoba; 18% Plate and Russian; 30% Hungarian, Moroccan and Australian; 15% weak German. Agene treated.	559
404	399	Blend: -ditto- but straight-run flour.	579
399	415	Blend: 25% No. 1 Manitoba; 25% No. 5 Manitoba; 30% mild Russian; 25% weak German. Treated heat-treatment and bromate. Bleached electric bleach (NO_2).	617
397	404	Blend: 30% Nos. 1 and 2 Manitoba; 15% No. 5 Manitoba; 25% Plate and mild Russian; 25% Hungarian; 5% German. Agene treated.	593
400	396	Milled from 100% good strength Plate wheat. Treated Agene.	469
403	418	Milled from 100% medium strength Russian wheat. Heat-treatment.	662
414	397	A mixture of 50% of the medium strength Z1/415 and 50% weak English.	575
402	414	Milled from 100% Yeoman wheat. Unbleached and untreated.	554
396	398	Weak English. Treated Agene.	412
398	402	Weak French wheat. Unbleached and untreated.	505

[1] Description of flours and mean loaf volumes apply to the *a priori* arrangement of samples.

Studies Conducted in Dover, England

Portions of the two series of flours were first submitted to the ordinary routine analysis in Dover as is normally carried out on all samples received.

An outline of the procedure employed for each test is given below, and the results obtained recorded in Table VI.

Moisture—Loss in Water Oven at 99 to 100° C.
Ash—Incinerated in electrically heated muffle-furnace controlled at 600° C.
Nitrogen—Kjeldahl method (see "Modern Cereal Chemistry," 2nd edition, page 322).
Maltose—Reported as percentage reducing sugars present after one hour's autolysis at 27° C. (see "Modern Cereal Chemistry," 2nd edition, page 351).
Colours (grade and bleach)—Method of Kent-Jones and Herd (1927).

TABLE VI

Analytical Data with Respect to the Flours Studied

Flour sample number	Moisture	Ash	Nitrogen	Protein (N×5.7)	Maltose	Grade figure	Bleach figure
	%	%	%	%	%		
			Winnipeg samples				
1	12.54	0.46	2.62	14.93	1.00	7.5[1]	9.5
2	12.88	0.47	2.20	12.54	1.03	7.5[1]	9.0
3	12.98	0.49	1.81	10.32	1.48	9.0	8.0
4	12.52	0.42	1.61	9.18	1.15	8.0	7.0
5	13.44	0.47	1.73	9.86	1.47	8.5	5.0
6	12.86	0.39	1.75	9.98	0.98	7.5	6.5
7	12.68	0.39	1.74	9.92	0.88	7.5	7.5
8	12.60	0.43	2.16	12.31	1.10	8.0	6.5
9	12.62	0.38	2.12	12.08	0.91	7.5	7.5
10	12.80	0.39	1.93	11.00	0.99	7.5	7.5
11	12.64	0.38	1.81	10.32	0.80	7.5	6.5
			Dover samples				
Z1/396	13.66	0.36	1.55	8.84	1.11	7.0	5.0
397	14.81	0.41	1.72	9.80	1.61	7.5	6.5
398	14.38	0.40	1.31	7.47	1.05	7.5	3.0
399	14.16	0.43	1.93	11.00	1.43	8.0	4.5
400	14.04	0.39	1.85	10.55	1.47	7.0	4.5
401	13.38	0.47	2.38	13.57	1.38	9.0	4.5
402	14.10	0.40	1.37	7.81	1.06	7.5	14.5
403	13.84	0.36	1.82	10.37	1.41	7.0	3.0
404	14.10	0.42	1.83	10.43	1.36	8.0	4.0
414	14.61	0.45	1.60	9.12	1.56	8.5	9.0
415	15.19	0.42	1.92	10.94	1.72	8.0	4.0
416	15.32	0.42	2.09	11.91	1.69	8.0	3.5
417	14.72	0.43	2.10	11.97	1.53	8.0	3.0
418	15.52	0.47	1.79	10.20	1.27	9.0	3.0

[1] The discrepancy between the ash content and the grade colour in these two samples would appear to be due to extraneous mineral matter of a sandy or gritty nature which could be separated.

For the full evaluation of samples, the following procedure is carried out at Dover:

(*a*) Chemical analysis.
(*b*) Baking test.
(*c*) Chopin Extensimeter, when desired or necessary.
(*d*) Brabender Farinograph, when desired or necessary.

The following information on these tests may be of interest:

Baking test: The procedure adopted for this test is that normally employed in these laboratories for testing practically all types of flours met with in the baking industry in Great Britain and, indeed, in the British Empire. Full details of the method are given in "Modern Cereal Chemistry," 2nd Edition, page 174. The fermentation system is a short and severe one and cottage loaves are invariably made, as tin loaves made in a laboratory bakery are sometimes misleading, *i.e.*, a big loaf might be obtained from a fairly soft and slack dough. Doughs for cottage loaves have necessarily to be made tighter than those for tin loaves and the weight of the top portion resting on the bottom emphasizes any weakness in the flour which might be unnoticed in a tin loaf made under the "ideal" conditions of a test bakery. No loaf measurements are made, the general external and internal appearance of the loaf merely serving to confirm the deductions made from the dough characteristics during fermentation. The test is performed by a test baker of many years' wide experience of flours from all over the world.

It scarcely need be said that the baker was in complete ignorance as to the origin of these samples and had no knowledge of any of the analytical results.

Chopin Extensimeter: This instrument has been described by Bailey and Le Vesconte (1924) and is an attempt to measure scientifically the force necessary to stretch and eventually to break a thin film of dough. The physical properties of the dough can thus be evaluated, provided of course the test is carried out under exactly standard conditions. The experience of the Dover Laboratories with this instrument is that, provided great care is taken to keep conditions always the same, the results given by this instrument are reasonably accurate and agree well with the experience of bakers, which is, all said and done, the thing which is wanted. It must be remembered, however, that the improvement brought about by chemical treatment is not recorded as no yeast fermentation takes place.

Brabender Farinograph: This instrument was also used in the tests. The force taken to mix a dough (this force, of course, varies as the mixing progresses) is measured by a dynamometer and a graph is recorded, the shape of which is characteristic of the nature of the flour. The controls on the apparatus are particularly good. The tests are carried out using 300 grams of flour and water to give a consistency on the graph of 600 units.

Experimental Results

The two series of samples were tested by the usual baking procedure

at Dover, by two variations of the American standard baking test, by the Brabender Farinograph, and by the Chopin Extensimeter. The two American methods employed were the normal basic method and the malt-phosphate-bromate formula (Larmour, Geddes, and Whiteside (1933)), in which 0.25 grams of malt (approximately 200° Lintner), 0.05 grams mono-ammonium phosphate and 0.001 grams potassium bromate are superimposed on the basic ingredients.

Admittedly the Dover results with the American technique, owing to the comparative inexperience with this method, may not be as accurate as the same tests carried out by more experienced workers in Winnipeg, but the results may be of interest in indicating the type

TABLE VII

ORDER OF DECREASING STRENGTH AS FOUND BY THE DOVER BAKING PROCEDURE

Winnipeg samples

Flour sample number	Water absorption	Baker's report
	per cent	
1	57.1	Dough fairly tough, lively and elastic and had good medium stability. Very good oven development. *Glutenous and strong flour.*
8	56.3	Dough had good medium stability and good liveliness and spring. Developed well. *Pleasing flour of very nice strength.*
3	57.1	Dough had good stability but poor liveliness and spring. Handled sluggishly. *A very nice strength but works abnormally, being rather "dead" in the dough.*
2	57.1	Dough possessed nice medium stability. Was lively and elastic and oven spring good. Crust little pale. *Pleasing locf of nice strength.*
5	55.4	Dough was lively, had nice spring and nice medium stability. Oven jump was good and crust colour fair. *Flour of nice strength.*
9	55.4	Dough had very nice spring but only medium stability and tended to slacken out. Developed in oven quite nicely but crust only fair. *A flour of nice strength but not very stable. Poor gasser.*
10	55.4	Dough had only fair stability and slackened out, although spring and liveliness were nice. Oven jump only fair and crust pale. *Flour of medium strength and low gassing power.*
7	55.4	Dough of medium stability and liveliness but spring very poor. Almost stopped gassing. Little oven development and very pale crust. *Flour of medium strength and of very poor gassing power.*
4	56.3	Dough of nice medium stability but badly lacking spring and liveliness. Lacked gassing power and oven jump only fair. Pale crust. *Flour of medium strength of poor gassing power.*
11	55.4	Dough had poor stability, was runny and had very poor gassing power. Very little oven jump and very pale crust. *A flour of medium strength which gives a runny dough of very poor gassing power.*
6	55.4	Dough of poor stability and lacked spring and elasticity. Poor gassing power and oven jump and crust pale. *Medium strength flour of poor gassing power.*

TABLE VII—(*Continued*)

Dover samples

Flour sample number	Water absorption	Baker's report
	per cent	
Z1/401	56.3	Dough was tough and elastic and possessed good medium stability. Spring and liveliness good. Oven development very good. Excellent well-built loaf. *Very strong and glutenous flour.*
Z1/417	56.3	Dough tough, good spring and liveliness and good medium stability. Developed well in oven. Strongly built loaf. *Not as srtong as Z1/401 but strong, glutenous flour.*
Z1/416	55.4	Dough had good spring and liveliness. Stability good medium. Oven development good. Loaf of good volume. *Flour of good strength.*
Z1/403	55.4	Dough fairly tough, nice spring, good liveliness and good medium stability. Developed well. *Flour of good strength.*
Z1/399	55.4	Dough lively and elastic and of nice medium stability. Produced well-built loaf. *Flour of similar strength to Z1/403.*
Z1/415	54.5	Dough had very good liveliness and spring and good medium stability. Loaf well developed. *Flour of very nice strength.*
Z1/400	54.5	Dough of nice medium stability. Good spring and very good liveliness. Oven spring good. *Pleasing flour of nice strength, similar to but trifle stronger than Z1/404.*
Z1/396	54.5	Dough of nice medium stability. Liveliness and spring good. Oven jump good. Crust colour only fair. *Flour of nice strength.*
Z1/404	53.6	Dough very lively. Spring good and stability nice medium. Developed well in oven. *Pleasing flour of nice strength.*
Z1/397	53.6	Dough had nice medium stability and showed fairly good spring. Developed well. *Generous working flour, not quite as strong as Z1/396 and Z1/404.*
Z1/418	53.6	Dough lively but of medium stability. Spring very fair. Oven spring satisfactory. *Flour of nice medium strength and not quite as strong as Z1/397.*
Z1/414	52.7	Dough of nice medium stability. Fairly lively; spring poor. Oven development fair. Crust pale. *A weak flour of low gluten content but stronger than Z1/398 and Z1/402.*
Z1/402	51.8	Nicely lively but poor spring. Little more stability than Z1/398. Seemed to handle little drier. Fair oven spring. *Very weak flour but not so runny as Z1/398.*
Z1/398	51.8	Stability bad. Nicely lively but very poor spring. Poor oven development; crust pale. *Very weak, soft flour.*

of variation found between laboratories in Europe and in America attempting to use the same baking procedure. Of course, correct baking equipment for the test (rotary oven, *etc.*, with controlled temperature, correct tins, *etc.*) was employed and, as can be seen from the previous paper (Kent-Jones, 1934), a larger number of flours has been tested in Dover using this procedure.

In Table VII the samples are placed in order of decreasing strength as assessed by the Dover baking method and with each sample the more important conclusions are given as they appeared in the baker's report book.

The loaf volumes obtained by the two variations of the American standard test are given in Table VIII in decreasing order, while the

TABLE VIII

LOAF VOLUMES IN DECREASING ORDER OBTAINED BY BASIC AND MALT-PHOSPHATE-BROMATE FORMULAS [1]

Basic formula		Malt-phosphate-bromate formula	
Sample number	Loaf volume	Sample number	Loaf volume
	Cc.		*Cc.*
	Winnipeg samples		
1	569	1	844
5	563	2	644
8	511	8	586
9	500	10	583
4	494	9	576
2	484	11	570
6	474	7	558
10	469	5	534
3	464	3	500
11	449	4	482
7	429	6	411
	Dover samples		
Z1/401	626	Z1/416	623
404	600	401	593
415	570	397	588
403	562	418	558
400	553	417	545
399	550	400	543
397	538	414	538
416	524	415	530
417	520	396	518
418	505	399	515
396	458	403	515
414	445	398	440
398	440		

[1] Owing to insufficiency of material, we were unfortunately unable to subject sample Z1/402 to either American standard baking test or to the Chopin Extensimeter. Also, we were unable to subject Z1/404 to the malt-phosphate-bromate modification.

orders of strength as indicated by the Brabender Farinograph and Chopin Extensimeter curves are given in Table IX, along with the final English classification based on the combined results of the Dover baking tests and the Farinograph and Chopin Extensimeter curves. The final classifications were arrived at as follows: In the case of each method the samples were arranged in order of decreasing strength. The first sample (*i.e.*, the strongest as judged by that method) was awarded the same number of marks as there were samples in the series. The next sample was awarded one mark less, the next sample one mark less again, and so on until the last or weakest sample received one mark. The total number of marks received by each sample in the various methods concerned was then determined by addition and

the order of strength as judged by the combined methods was then the order obtained by arranging the samples according to their total marks.

TABLE IX

ORDER OF DECREASING STRENGTH AS INDICATED BY BRABENDER FARINOGRAPH AND CHOPIN EXTENSIMETER TESTS AND FINAL CLASSIFICATION [1]

Brabender Farinograph	Chopin Extensimeter	Final classification
	Winnipeg samples	
1	1	1
2	8	8
8	2	2
9	3	3
10	9	9
3	10	10
7	5	5
11	11	7
6	7	11
5	6	6
4	4	4
	Dover samples	
Z1/401	Z1/401	Z1/401
417	417	417
416	416	416
403	403	403
404	399	399
400	400	400
418	415	415
399	404	404
415	418	418
396	397	396
397	414	397
414	396	414
402	398	402
398		398

[1] The size of the sample did not permit Z1/402 to be examined on the Chopin Extensimeter but for ease of comparison this sample has been given an assumed position in the bottom place. This will make very little difference to misplacement figures, *etc.*, as no single or combined tests place it higher than two places above this.

Discussion by W. F. Geddes of the Results Obtained by Both Investigators

The results of the protein, ash, and diastatic activity determinations on corresponding samples by the Winnipeg and Dover laboratories are mainly in close agreement, but the same cannot be said of the strength classification of the flours.

For the purpose of comparison, the classifications of both sets of flours in order of descending strength, as indicated by their composition and by various test methods employed in the two laboratories are given in Table X. In order to secure a numerical measure of the classification inaccuracies by both laboratories, using different methods

of classification as standards for comparison, the difference between the serial number of the placing by the standard and of that under consideration, has been taken for each sample, allowance being made

TABLE X

CLASSIFICATION OF FLOURS IN ORDER OF DECREASING STRENGTH AS INDICATED BY DIFFERENT METHODS

Flour sample number	Classification					
	a priori	Dominion Grain Research	Kent-Jones' final	Kent-Jones' baking test	Brabender Farino-graph	Chopin Exten-simeter
	Samples supplied by the Dominion Grain Research Laboratory					
1	1	1	1	1	1	1
2	2	2	8	8	2	8
3	8	8	2	3	8	2
4	9	9	3	2	9	3
5	10	10	9	5	10	9
6	3	7	10	9	3	10
7	11	5	5	10	7	5
8	7	3	7	7	11	11
9	6	11	11	4	6	7
10	5	6	6	11	5	6
11	4	4	4	6	4	4
	Samples supplied by Kent-Jones					
1	401	401	401	401	401	401
2	417	416	417	417	417	417
3	416	418	416	416	416	416
4	403	417	403	403	403	403
5	400	415	399	399	404	399
6	399	404	400	415	400	400
7	415	399	415	400	418	415
8	404	397	404	396	399	404
9	396	400	418	404	415	418
10	418	403	396	397	396	397
11	397	414	397	418	397	414
12	414	402	414	414	414	396
13	398	396	402	402	402	398
14	402	398	398	398	398	—

for the bracketing of those samples which are found to be equal in strength. The results of this analysis are given in Table XI.

Considering first the relative misplacings by the different methods, using the *a priori* classification as the standard of reference, it will be noted that, in the instance of samples supplied by Winnipeg, the Brabender Farinograph classified nine samples correctly, the remaining two being out by only one place; the Winnipeg laboratory classified six samples correctly, two being out by one and three by two places. The Kent-Jones' final classification, based on the mean placing by the Farinograph, the Extensimeter, and the English baking test, correctly placed five samples; of the remainder three were out one place, two, two places; and one, three places. The English baking test, however,

TABLE XI

Comparative Classification Inaccuracies Using Various Methods of Classification as Standards [1]

Flour sample number	D. G. R. classification	Kent-Jones' final classification	Kent-Jones' bake	Brabender	Chopin	D. G. R. classification	Kent-Jones' final classification	Kent-Jones' bake	Brabender	Chopin	D. G. R. classification	Kent-Jones' final classification	Kent-Jones' bake	Chopin
	Samples supplied by Dominion Grain Research Laboratory													
	Standard = *a priori*					Standard = Dominion Grain Research final					Standard = Brabender			
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	1	0	0	0	1	2	0	1	0	1	1	1
8	0	0	0	0	0	0	1	1	0	1	0	1	1	1
9	0	1	2	0	1	0	1	2	0	1	0	1	2	1
10	0	1	2	0	1	0	1	2	0	1	0	1	2	1
3	1	2	3	0	2	0	3	5	1	3	1	2	3	2
11	2	2	3	1	1	0	0	1	1	1	1	1	2	0
7	2	0	0	1	1	0	2	2	1	3	1	1	1	2
6	1	1	2	0	1	0	0	1	1	0	1	1	2	1
5	2	3	5	0	3	0	0	2	2	0	2	3	5	3
4	0	0	2	0	0	0	0	2	0	0	0	0	2	0
"Misplacing figure"	8	10	20	2	10	0	9	20	6	11	6	12	21	12
Number of samples correctly placed	6	5	3	9	4	11	5	1	6	4	6	2	1	3
Unit misplacing figure	.7	.9	1.8	.2	.9	0	.8	1.8	.5	1.0	.5	1.1	1.9	1.1
Unit samples correctly placed	.5	.4	.3	.8	.4	1.0	.4	.09	.5	.4	.5	.2	.09	.3
	Samples supplied by Kent-Jones													
	Standard = *a priori*					Standard = Kent-Jones' baking test					Standard = Brabender			
401	0	0	0	0	0	0	0	0	0	0	0	0	0	0
417	2	0	0	0	0	2	0	0	0	0	2	0	0	0
416	1	0	0	0	0	1	0	0	0	0	1	0	0	0
403	5	0	0	0	0	5	0	0	0	0	5	0	0	0
400	4	1	2	1	1	2	1	0	1	1	3	0	1	0
399	0	1	1	0	1	2	0	0	3	0	1	3	3	3
415	1	0	0	1	0	1	1	0	3	1	4	1	3	2
404	0	0	1	1	0	3	1	0	4	1	1	2	4	3
396	2	0	1	0	1	4	2	0	2	4	3	0	2	2
418	6	0	0	2	0	8	2	0	4	2	4	2	4	2
397	1	0	0	0	0	2	1	0	1	0	3	0	1	1
414	1	0	0	0	0	1	0	0	0	1	1	0	0	1
398	1	1	1	1	0	0	0	0	0	1	0	0	0	1
402	2	1	1	1	0	1	0	0	0	0	1	0	0	1
"Misplacing figure"	26	4	7	7	3	32	8	0	18	11	29	8	18	16
Number of samples correctly placed	3	10	8	8	11	2	8	14	7	7	2	10	7	5
Unit misplacing figure	1.9	.3	.5	.5	.2	2.3	.6	0	1.3	.8	2.1	.6	1.3	1.1
Unit samples correctly placed	.2	.7	.6	.6	.8	.1	.6	1.0	.5	.5	.1	.7	.5	.4
	Both sets of samples													
"Misplacing figure"	34	14	27	9	13	32	17	20	24	22	35	20	39	28
Number of samples correctly placed	9	15	11	17	15	13	13	15	13	11	8	12	8	8

[1] Each value given in the table is the difference between the serial number of the placing of the flour by the standard and of the method of classification under consideration, allowance being made for the bracketing of those samples which are found to be of equal strength.

only classified three samples correctly. Of those wrongly placed, one was out one place; four, two places; two, three places; and one, five places.

As regards the samples supplied by Kent-Jones, the best classification was given by the Chopin Extensimeter, closely followed by the Kent-Jones' final classification; the Kent-Jones' bake and the Brabender Farinograph were next, while the Winnipeg laboratory's final classification only placed three samples correctly.

Comparing the relative success of the two laboratories in classifying each other's samples, it will be noted that Kent-Jones, on the basis of his final classification, was decidedly more successful in placing the Winnipeg flours than was the Winnipeg laboratory in placing the Dover samples; however, the Canadian classification was based entirely on baking tests. One of the fundamental criticisms of Kent-Jones was in regard to the manner in which baking tests were conducted and interpreted in America. In place of standardizing baking test procedures, in which the volumes of the finished loaves are taken as the principal criterion of strength, Kent-Jones prefers to conduct the test in his own way and to base his judgment of relative strength principally on the behaviour of the fermenting doughs. The Brabender Farinograph and the Chopin Extensimeter cannot be classed as distinctly English methods and the writer (Geddes) requested that, if at all possible, these mechanical methods of testing be employed for comparison of the results with those of the English and Canadian baking test methods, more especially in view of the suggestion by Kent-Jones (1934) that progress is most likely to be made by a more thorough study of the physical properties of the doughs.

With these considerations in mind, it would seem that a fairer comparison of the relative success of the two laboratories in classifying each other's samples would be to consider the relative placings by the English and Canadian baking tests. On this basis, and using the *a priori* classifications as the standards of comparison, the English baking test only placed three of the eleven Winnipeg samples correctly, the numerical value of the misplacings being 20. On the other hand, the Canadian baking tests only placed three of the fourteen English samples correctly, the numerical value of the misplacings being 26.

There does not appear to be a great deal to choose between the relative success of the two laboratories in placing each other's samples by the baking test, although on the whole, Kent-Jones did slightly better than the Canadian laboratory, if the *a priori* classification is taken as the standard of reference. Both laboratories made a few rather serious errors in the relative placings of each other's flours. For example, Kent-Jones classified sample No. 5, milled from 100%

English Yeoman as fifth in order of strength, placing it above a number of samples, notably Nos. 9 and 10, consisting of blends of high protein Canadian with French; also sample No. 3 consisting of 100% low protein No. 1 Northern was placed higher than sample No. 2, which was milled from Average No. 1 Northern of over 2.0% higher protein content. In both instances the Brabender classification is in agreement with their *a priori* arrangement. On the other hand, the Winnipeg laboratory for example, placed sample No. Z1/418, a heat-treated flour milled from medium strength Russian, third in order of strength above No. 417 which was milled from 100% Canadian wheat of approximately 2.0% higher protein content; also sample No. Z1-403 milled from a blend of Canadian, Argentine, Russian and Hungarian wheat was classified in ninth place instead of the *a priori* fourth place. The Brabender Farinograph, however, classified No. 418 higher than the *a priori* order and No. 403 the same as that indicated by Kent-Jones.

It is of special interest to note that the Brabender Farinograph classified 17 of the 25 samples studied in exact agreement with their *a priori* arrangement, and the Chopin Extensimeter accurately classified 15 on the same basis, the latter instrument being more successful with the English samples than the Brabender Farinograph. The physical methods of dough testing gave a more accurate classification than either the English or Canadian baking methods, assuming that the *a priori* orders of strength are correct. In this connection, it is important to note that, in both series, the *a priori* rating of the flours closely follows their protein content; thus for the Winnipeg samples the rank order correlation between the *a priori* classification and the placing of the flours on the basis of decreasing protein content is + 0.97, and for the Dover samples + 0.92. Actually, then, the classification of the samples on the basis of protein content alone would have given a fairly accurate strength classification, particularly in the instance of the Winnipeg samples. It is, therefore, particularly striking that the physical methods of dough testing classify the flours essentially in the order of their protein content. Thus, if the ranking of the flours by the Brabender Farinograph is compared with that for protein content, the Winnipeg samples give the very high rank order correlation of + 0.98 and the Kent-Jones' samples of + 0.86. While, undoubtedly, the physical measurements are influenced to some extent by variations in protein quality, the results in this series show that the quality factor is largely obscured by the quantity factor, the latter having much the greater influence. The same statement, of course, applies to the baking tests. Actually, the classification of the Winnipeg samples on the basis of protein content provides as satisfactory a

basis for strength rating as the combined results of the six baking methods selected.

The discussion of the relative success of the English and American baking methods in classifying the flours thus far has been limited to the results obtained by the various methods using the *a priori* classification as the standard for comparison, but there is no definite assurance that this is correct, particularly in the instance of the English samples where the complexity of the blends and flour treatment admittedly rendered the *a priori* classification exceedingly difficult. There are two groups of three flours each which Kent-Jones was unable to classify, and from the results of the tests conducted, every method of classification placed sample No. 402 above No. 398, which is contrary to the *a priori* order. Two other standards of reference have accordingly been selected, in order to compare the utility of the various methods of classification. In one of these the Canadian final classification, which is based entirely on baking data, was taken as correct for the Canadian samples and the Kent-Jones' baking test for the English samples; in the other, the classifications given by the Brabender Farinograph were employed as typical of physical measuring instruments. The Chopin results could not be used, since one of the English samples was not tested with this instrument.

Employing the respective baking tests as the standards for the English and Canadian samples, both Kent-Jones' "final" and the Winnipeg laboratory accurately classified 13 of the 25 samples, the "misplacing figure" for Winnipeg being 32 as compared with 17 for Kent-Jones. Further, comparing the relative success of the English and Canadian baking tests, Kent-Jones accurately classified 15 as compared with 13 for the Winnipeg laboratory, the respective misplacing figures being 20 and 32. It should be pointed out that, in these comparisons, there were 14 samples in the English group and only 11 in the Canadian, thus giving Kent-Jones the benefit of three additional correct placings.

In the instance of the Brabender Farinograph as the standard, there is no purpose in using the Kent-Jones' final classification, since this includes the Brabender results. The English and Canadian baking tests each place 8 of the 25 samples correctly, while the "misplacing" figure is 4 units lower for the Winnipeg laboratory, indicating that its placings are slightly better.

From this analysis there is little to choose between the English and Canadian baking methods in evaluating the series as a whole, but it is quite apparent, on the basis of either the *a priori* or Brabender classifications, that each investigator has been more successful in placing the flours with which he is accustomed to working, indicating

that the methods in use in the two countries are quite dependable for the purpose for which they have been designed. In this connection it is interesting to note that Kent-Jones has been more successful in classifying the Winnipeg samples by applying the malt-phosphate-bromate formula recommended to him by the junior author than he was by the Dover baking test. This is shown in Table XII in which

TABLE XII

COMPARATIVE CLASSIFICATION INACCURACIES FOR KENT-JONES' TESTS EMPLOYING ENGLISH BAKING TEST AND MALT-PHOSPHATE-BROMATE FORMULA (NO. 4)—WINNIPEG SAMPLES

	Standard = *a priori*		Standard = D. G. R. "Final"		Standard = Brabender	
Flour sample number	English bake	M. P. B. (No. 4)	English bake	M. P. B. (No. 4)	English bake	M. P. B. (No. 4)
1	0	0	0	0	0	0
2	1	0	2	0	1	0
8	0	0	1	0	1	0
9	2	1	2	1	2	1
10	2	2	2	2	2	2
3	3	2	5	1	3	3
11	3	1	1	3	2	2
7	0	0	2	1	1	0
6	2	2	1	1	2	2
5	5	2	2	0	5	2
4	2	1	2	1	2	1
"Misplacing figure"	20	11	20	10	21	13
Number of samples correctly placed	3	4	1	4	1	4

the comparative placings of the Winnipeg samples by the two baking methods are given using the *a priori*, Dominion Grain Research Laboratory "final," and the Brabender classifications as standards, respectively. In preparing this table, 30 cc. was taken as a significant difference between the loaf volumes reported by Kent-Jones in Table VIII.

Since the complete series of Dover samples was not baked by the malt-phosphate-bromate formula in Kent-Jones' laboratory, it has not been possible to make the same comparison as with the Winnipeg samples, although it is quite obvious from a consideration of Tables VII and VIII that the English baking test classified the Dover samples in closer agreement with the *a priori* order.

It has already been stated that, considering the entire series of flours, there is little to choose between the English and Canadian baking methods for evaluating flour strength; it must be admitted that the English classification was apparently arrived at after only one baking test, while the Canadian classification was based on the mean

results by six procedures involving twelve individual bakings of each flour. An examination, however, of Tables III and IV shows that certain individual methods, notably the high yeast-sugar-bromate (No. 6) and the malt-phosphate-bromate 3-minute Hobart-Swanson (No. 17) would have sufficed to give a highly accurate classification of the Winnipeg samples. These two methods have been developed by Canadian laboratories for evaluating wheat strength, which is quite a different matter from classifying commercial flours as to their strength and suitability for specific bakeshop conditions.

In testing wheat quality, an effort must be made to measure the potentialities of a raw material which may be submitted to a wide range of treatment in commercial milling and baking practices. In testing Western Canadian hard red spring wheats, we are dealing with very strong wheats which, from the standpoint of handling quality and dough stability, would show little differentiation but differ largely in bread-making quality as reflected by water absorption and loaf volume. In testing wheat strength, the flours are experimentally milled and usually baked without treatment with bleaching agents and after only a comparatively short period of storage. In the early stages of this work in Canada, it was soon found that the methods normally employed for testing finished flours were unsatisfactory. In the first place, the diastatic activity of experimentally milled flours is lower than that of flours commercially milled from the same wheats, and it is extremely important to ensure adequate gas production to preclude yeast starvation. Moreover, the gluten of strong, freshly-milled untreated flours requires modifications in the baking formula or procedure to provide for optimum development so as to permit the maximum expansion of which the dough is capable. This may be most conveniently accomplished by severe mixing and by the addition of oxidizing agents, such as potassium bromate, *etc.*, to the baking formula. While prolonged fermentation has the same general effect on loaf volume, it is inconvenient and there is a distinct danger of a deficiency of gas production; for this reason it is preferable to use a fixed fermentation time and increase the extent of fermentation by using a high percentage of yeast in conjunction with a high sugar level. While under such conditions the internal loaf characteristics bear little relation to those desired commercially, this is not considered important in determining inherent strength, since experience has shown that a flour which is capable of producing large, bold, well-shaped loaves under these experimental conditions, possesses high inherent strength. The fundamental philosophy underlying the methods of wheat testing employed in this laboratory, therefore, is that baking formulas and procedures must be employed which preclude

yeast starvation and develop the gluten so as to permit maximum panary expansion and oven spring of the dough.

In order that the latter may be accomplished, the various factors affecting gluten development, either singly or combined, must be gradually varied over a sufficiently wide range. If judged by the basic procedure, by the bromate test, or by response to mechanical mixing respectively, some experimentally milled flours would be rated as inferior or lacking in strength but when given the proper combination of treatments such flours may exhibit a high potential strength. The experimental conditions necessary to attain this, and the variations in loaf volume accompanying the changes in baking formula or procedure, will reveal the optimum conditions for the use of the flour. It is thus a question of discovering the particular environment required and a flour should not be rated as inferior unless exhaustive supplementary tests reveal no way in which the possibilities indicated by its protein content can be realized by methods now readily available in commercial practice. Under the optimum environmental conditions for panary expansion and oven spring, loaf volume is regarded as an eminently satisfactory index of baking strength and possesses the advantage that it can be measured and recorded with considerable accuracy.

Fisher (1935) has recently supported the view that in testing flour milled from wheats of the same type, loaf volume may be a useful criterion of strength.

While the same principles would apparently apply in testing the baking potentiality of commercially milled flours, the problem of the mill or bakery chemist is not so much a matter of measuring the maximum capabilities of a flour as it is of determining its suitability for a particular set of baking conditions, so that the viewpoint and the type of information desired from a baking test is quite different from that of the cereal chemist testing wheat strength. It does not seem that Kent-Jones uses the term "strength" in the same sense as the writer (Geddes) and, in his baking tests, major emphasis is placed on such factors as toughness, elasticity, freedom from stickiness, dough stability, *etc.* While such factors are usually associated with strong flours, it is quite possible for two flours to be similar in these characteristics and yet the one to possess much higher potential strength than the other. This is exemplified in a number of Kent-Jones' placings but particularly in his placing of flour No. 3, a low protein flour milled from No. 1 Northern wheat, higher than sample No. 2, also milled from No. 1 Northern wheat but of 2% higher protein content. From the standpoint of inherent strength and ability to support weak flour in a blend, sample No. 2 would receive the higher rating. In testing

commercial flours of unknown origin and treatment for baking potentiality, along the lines adopted by the writer (Geddes) for evaluating wheat strength, a part of the modification of the gluten may have already taken place by natural or artificial aging or by heat treatment, and may also have been provided for by the addition of solid oxidizing agents, such as potassium bromate, to the flour. In such instances, less gluten modification is required in the actual baking and it is not surprising that the baking methods selected for the classification of the Winnipeg samples were not suitable for the Dover samples, since the latter had been subjected to varying treatments. A more satisfactory placing of the flours would have been arrived at by considering the maximum volumes yielded by any given flour without respect to baking formula or procedure.

While the English test advocated by Kent-Jones appears to be rapid in the hands of an experienced operator, it suffers certain drawbacks. The method requires the services of a highly skilled expert baker whose reports are entirely based on personal opinion, while the American methods may be learned and performed by an intelligent laboratory technician in a relatively short period of time, since the test itself is standardized and the major strength characteristic, namely, loaf volume, is capable of quantitative measurement. In other words, little is left to the judgment of the operator, which, as pointed out by Jorgensen (1933) is a dangerous practice, as even a very capable baker cannot, without a very considerable waste of time, vary such factors as punching, fermentation time, proofing time, *etc.*, in a rational way, so that he is certain of getting the best results. Another serious drawback of the Kent-Jones' procedure is the lack of permanent quantitative data which would permit future reference for comparative purposes. It would seem difficult, if not absolutely impossible, to combine the results of one day's baking on a series of flours with those of another series baked some time hence, if it became necessary to arrange the two sets of samples into a single classification. It would appear to be necessary to bake both sets of flours at the one time in order to obtain information on the relative dough characteristics of the various flours, since the general descriptive terms employed are so limited in number and difficult to interpret on a definite strength basis. Is, for example, "a generous working flour" better than or inferior in quality to "a pleasing flour of nice strength"? In much of the work in which the writer (Geddes) is engaged it frequently becomes necessary to compare the baking strengths of flours under examination with those of other samples tested some months previously. It is realized, even when these tests are conducted by the same operator using standardized baking procedures under presumably

similar conditions, that there may be variations in the general level of results obtained at different periods of time, which must be taken into consideration in combining the data, yet such a practice appears to be eminently more feasible when quantitative data are available. It is the usual practice in Canadian laboratories to hold a sufficient quantity of one flour in cold storage for use as a standard over a period of several months; this standard flour is baked with each series under examination, small quantities being removed from storage at frequent intervals. By comparing the loaf volumes of the standard flour for the two series it is desired to combine into a single classification, it is possible to detect whether the general level of the baking results has varied.

In regard to the findings of Kent-Jones (1934) on the utility of the basic test under English conditions, his experiences parallel those obtained in Canadian laboratories as reviewed by Geddes and Larmour (1933), and these have already been mentioned by Geddes, Larmour, and Mangels (1934) in their comments on the Kent-Jones' criticisms.

The loaf volumes by the basic test have been shown by a number of workers to be correlated with flour diastatic activity and, in the instance of flours experimentally milled from strong wheats, the gluten is not sufficiently developed, so that the results are not definitely interpretable in terms of flour strength. While the test is designed to serve as a reference point, as indicated by the name, the writer (Geddes) personally feels that to be truly a basic test, sugar should be omitted from the formula. Under such conditions, the test would more satisfactorily reflect variations in flour diastatic activity than at present. By superimposing gas-producing supplements and gluten-developing agents, singly and combined, the results as compared with the more truly basic formula would indicate whether the flour is deficient in gassing power and the extent of gluten development necessary. The baking test, however, is rather a cumbersome method of estimating flour gassing power and if a basic test, from the standpoint of strength differentiation alone, is the object, then the basic formula should contain a sufficiency of gas-producing supplements to preclude yeast starvation for the percentage yeast and fermentation time employed.

Summarizing this discussion, the writer (Geddes) holds no particular brief for any special method of flour testing whether it be by a baking test or by other means, but the present study does not indicate that the English baking method as practised by Kent-Jones is in any way superior to the procedures employed in America for classifying flours on a strength basis, and as already pointed out, would be entirely unsuitable for the work undertaken in this laboratory. The out-

standing feature of this collaborative study has been the relation between protein content and the classification of the flours by the Brabender Farinograph, particularly in the instance of the Winnipeg samples. Since the *a priori* arrangement of the flours, in general, followed their protein content, the Farinograph placings were much more satisfactory in placing the flours in line with the *a priori* basis than either the English or Canadian baking tests, taking the series as a whole.

Discussion by D. W. Kent-Jones of the Results Obtained by Both Investigators

It is only fair to state at the commencement of this discussion that the writer (Kent-Jones) has had an opportunity of seeing the draft discussion by Geddes of the results. Before examining the actual results it would be as well to remember the scope of the writer's earlier paper in 1934, the criticism in which gave rise to this collaborative work which has undoubtedly been of value.

The earlier paper was purely an effort to apply the so-called standard baking test to distinguish flours milled under European conditions and to examine its value (taking loaf volume as the main criterion) to the chemist who has to apprise in England, for example, the baking value of different commercial flours. The writer (Kent-Jones) was not so concerned with the value of the test in America.

The main points the writer queried were:

(1) Was the test really a standard one?

(2) Was the test able to differentiate between small differences in blends such as the addition of 5 to 10% of English flour, as would be expected in commercial practice?

(3) Was the present day work on the standardizing of the baking test helpful and would it not be better to attempt standardization along the lines of mechanical measurements of doughs?

The writer submits that the essential result of this collaboration is to justify these queries.

With respect to the first point as to whether the so-called standard test is standard, Geddes performs in this series no less than nineteen tests and then selects six of these. The average placing of these six is chosen for comparison against the simple baking of the English test. It is claimed that as the variations have certain points in common with the original basic method they are still essentially standard. Nevertheless the results, due to the imposing of special modifications on the basic test, are often very different from those obtained by the basic test; what advantage, therefore, remains from having certain

features of the basic test retained? [3] Each variation introduced may completely alter the assessment of a particular flour. This point, however, is not very important now that attention has been directed to it.

The second and third points are of much more consequence and the following discussions will, it is thought, help to clarify the situation.

As Geddes has rightly pointed out, some of the standard baking procedures scarcely differentiate many flours which ought to be differentiated (see Table IV) and it is doubtful if even the most appropriate of the standard procedures would tell the chemist sufficient about the types of commercial flours met with in England. Attention is particularly drawn to the unsatisfactory results obtained by the various American standard methods with respect to samples Nos. 415 and 397. Sample No. 397 was a mixture of 50% No. 415 and 50% of a weak English and it was, therefore, very much weaker than No. 415. Of the nineteen baking methods employed there was no significant difference (taking 30 cc. as the significant figure in this case) in no less than twelve of them and in one, the favoured malt-phosphate-bromate (No. 4) the largest loaf volume came from the much weaker flour.

In the Geddes discussion emphasis is laid the whole time on the comparison of the average results of the six methods selected from nineteen against the single English baking test. Even then the results are scarcely flattering to the average of the six selected methods. Actually, however, the comparison should not be directed to the Dover baking results but to the final Dover assessment which takes into account not only the baking test but the other tests which are applied and which the writer has suggested are of extreme importance and much more adaptable to standardization.

To make this point clear it is important to recall the actual words used in the writer's (Kent-Jones) previous paper (1934) when speaking of the Dover baking test—

"It is a baking test which must be adaptable and the conclusions are always supplemented by other tests."

Then the author is inclined to think that too much detail and statistics are being dealt with in the Geddes discussion so that there is danger that the main and essential facts will be lost. Geddes, representing the American point of view, has taken as his "yardstick," loaf volume from certain selected results, while the Dover "yardstick," which is dough characteristics, comprises not only a baking assessment but

[3] As pointed out by Geddes, Larmour and Mangels (Cereal Chem. 11: 66–69) and Blish (Cereal Chem. 11: 70–73, 1934) the standard baking test serves as a skeletal procedure upon which it is possible to superimpose variations in either formula or procedure, thus securing a quantitative measure of the effect of the variables introduced and making it possible to obtain the maximum of information regarding the baking characteristics of the flour. (W F.G.)

also other methods. There is no reason why the Dover additional methods other than the "bake" should be prohibited from entering into the final assessment. The writer's previous paper pointed out that the American test was not satisfactory for European flours and stated that better results were obtained by his own method based on dough characteristics. It further pointed out that most advance could probably be made by the use of dough testing instruments.[4] The comparison of the results in this paper should, therefore, be between the final judgments, each being based on the full resources available at each laboratory for normal use.

Then as regards the comparisons, what standards should be adopted? The writer (Kent-Jones) thinks that misleading results may be obtained by some of the Geddes methods of comparison. It seems obvious, as indeed was the original intention of the paper, that the standard should be the *a priori* order, even though this may not be absolutely accurate. In this discussion, therefore, the only standards taken will be the *a priori* standards selected by each of the authors in turn who had special knowledge of the blends, *etc.* Further, for simplification, the Geddes system of misplacement values, *etc.*, will be adopted.

The crucial test will be the comparison of the unknown Dover samples as assessed by the final six selected baking test methods of Geddes, taking the Dover *a priori* order as standard which was settled previously but which was unknown to Geddes, against the combined Dover assessment of the unknown Winnipeg samples, the standard for comparison again being the previously determined *a priori* standard, which at the time was unknown to the author. In case there is any thought that there is an attempt to cover up the results of the actual Dover baking test, these will also be given.

Perhaps the fairest assessment may be obtained by a comparison of the results obtained on the whole twenty-five samples (eleven from Geddes and fourteen from Dover) using the *a priori* standards. It seems illogical to use either the final Winnipeg baking or the Dover baking as the standard.

It is agreed that the *a priori* list may not be perfectly accurate. Geddes, for example, has queried the Dover *a priori* list and has suggested that Z1/418 should be placed higher than it was and that Z1/402 should be above Z1/398. These suggestions have been adopted on a revised *a priori* standard. This has meant the alteration of two

[4] "Cereal chemists, in general, freely admit that the baking test has many drawbacks and in America, as elsewhere, other means of evaluating the factors contributing to baking quality, such as mechanical measurements of doughs, are being carefully studied. As pointed out by Geddes, Larmour, and Mangels (Cereal Chem. **11**: 66–69, 1934) such measurements must be interpreted in terms of baking behaviour and hence, in the last analysis, baking tests must be employed as the standard of reference." (W.F.G.)

samples, one by one place and the other by two places, a total of three displacements.

Similarly the Winnipeg *a priori* standard is open to criticism, particularly in regard to sample No. 3 (a No. 1 Manitoba of low protein content) which is placed sixth in the *a priori* rating below a blend of 35% high protein No. 1 Manitoba Northern and 65% French, which is known to be poor, being much inferior to Yeoman. Actually, the writer would not hesitate to put flour No. 3, milled from a wheat of low protein but still graded as No. 1, third in the *a priori* list after the 100% average No. 1 Northern. In this respect and in fairness to the Dover baking, it should be remembered that the sample was reported upon as "abnormal." It was, therefore, difficult to place from an ordinary strength point of view. This is important as a large proportion of the error in the Dover baking, which shows up so much in the statistical analysis, is due to this sample, the abnormality of which was noted. On the other hand, there is evidence that the Yeoman in this series is particularly good and so, endeavouring to meet all points of view as much as possible, the low protein No. 1 Northern is assessed fourth in the revised *a priori* list just below the 50% high protein No. 1 Northern and 50% Yeoman. It should be noted that the Dover baker did report on sample No. 3 being somewhat abnormal. The only other alteration suggested is the higher placing of sample No. 5, the 100% Yeoman. Actually, the author thinks it might at least be assessed above sample No. 6 instead of below. Hence the total change in the revised *a priori* list is two samples (as in the revised Dover *a priori*) one sample two places and one sample one place.

TABLE XIII

WINNIPEG SAMPLES

Standard	Standard = Original *a priori*					Standard	Standard = Revised *a priori*				
	Winnipeg	Dover final	Dover bake	Brabender	Chopin		Winnipeg	Dover final	Dover bake	Brabender	Chopin
1	0	0	0	0	0	1	0	0	0	0	0
2	0	0	1	0	0	2	0	0	1	0	0
8	0	0	0	0	0	8	0	0	0	0	0
9	0	1	2	0	1	3	3	0	1	2	0
10	0	1	2	0	1	9	1	0	1	1	0
3	1	2	3	0	2	10	1	0	1	1	0
11	2	2	3	1	1	11	2	2	3	1	1
7	2	0	0	1	1	7	2	0	0	1	1
6	1	1	2	0	1	5	1	2	4	1	2
5	2	3	5	0	3	6	0	0	1	1	0
4	0	0	2	0	0	4	0	0	2	0	0
Misplacing figure	8	10	20	2	10		10	4	14	8	4
Number of samples correctly placed	6	5	3	9	4		5	9	3	4	8
Unit misplacing figure	.7	.9	1.8	.2	.9		.9	.35	1.3	.7	.35
Unit samples correctly placed	.55	.45	.3	.8	.35		.45	.8	.3	.35	.7

TABLE XIV
DOVER SAMPLES

Standard	Standard = *a priori*					Standard	Standard = Revised *a priori*				
	Winnipeg	Dover final	Dover bake	Brabender	Chopin		Winnipeg	Dover final	Dover bake	Brabender	Chopin
401	0	0	0	0	0	401	0	0	0	0	0
417	2	0	0	0	0	417	2	0	0	0	0
416	1	0	0	0	0	416	1	0	0	0	0
403	5	0	0	0	0	403	5	0	0	0	0
400	4	1	2	1	1	400	4	1	2	1	1
399	0	1	1	0	1	399	0	1	1	0	1
415	1	0	0	1	0	415	1	0	0	0	0
404	0	0	1	1	0	418	3	0	2	0	0
396	2	0	1	0	1	404	0	0	0	1	0
418	6	0	0	2	0	396	2	0	2	0	1
397	1	0	0	0	0	397	2	0	0	0	0
414	1	0	0	0	0	414	1	0	0	0	1
398	1	1	1	1	0	402	1	0	0	0	1
402	2	1	1	1	0	398	0	0	0	0	1
Misplacing figure	26	4	7	7	3		22	2	7	2	6
Number of samples correctly placed	3	10	8	8	11		4	12	10	12	8
Unit misplacing figure	1.85	.3	.5	.5	.2		1.6	.15	.5	.15	.4
Unit samples correctly placed	.2	.7	.6	.6	.8		.3	.85	.7	.85	.6

TABLE XV
COMBINED RESULTS OF ALL TWENTY-FIVE SAMPLES

	Standard = *a priori*				
	Winnipeg	Dover final	Dover bake	Brabender	Chopin
Misplacing figure	34	14	27	9	13
Number of samples correctly placed	9	15	11	17	15
Unit misplacing figure	1.35	.55	1.10	.35	.50
Unit samples correctly placed	.35	.6	.45	.65	.60
	Standard = Revised *a priori*				
Misplacing figure	32	6	21	10	10
Number of samples correctly placed	9	21	13	16	16
Unit misplacing figure	1.30	.25	.85	.40	.40
Unit samples correctly placed	.35	.85	.50	.65	.65

It might justifiably be raised that a revised *a priori* standard is neither fair nor logical and the reader must bear this in mind. On the other hand, it does seem to the writer (Kent-Jones) that what is wanted is as much real guidance and light on the subject of the various strengths of the flours as possible so that a proper comparison of the methods employed by Dover and Winnipeg can be obtained for future guidance and it is suggested that the revised *a priori* standard gives this.

Tables XIII, XIV, and XV, which are similarly constructed to Table XI, give these keynote comparisons in a simple way.

Geddes' assessment of the unknown Dover samples should first of all be compared against the Dover assessment of the unknown Winnipeg samples.

	Winnipeg assessment Dover samples		Dover assessment Winnipeg samples			
			a priori standard		Revised *a priori* standard	
	a priori standard	Revised *a priori* standard	Dover final	Dover bake	Dover final	Dover bake
Unit misplacing figure	1.85	1.6	0.9	1.8	0.35	1.3
Unit samples correctly placed	0.2	0.3	0.45	0.3	0.8	0.3

As regards the Dover final assessment, which it is suggested is really the one in question, whether the standard taken is the *a priori* or the revised *a priori*, the results are strikingly better than the Winnipeg assessment. Even the simple and single Dover baking is superior to the average of the six selected Winnipeg tests.

Then the comparison might fairly be made similarly with the total samples.

	Winnipeg assessment total samples		Dover assessment total samples			
			a priori standard		Revised *a priori* standard	
	a priori standard	Revised *a priori* standard	Dover final	Dover bake	Dover final	Dover bake
Unit misplacing figure	1.35	1.30	0.55	1.10	0.25	0.85
Unit samples correctly placed	0.35	0.35	0.6	0.45	0.85	0.50

These results are even more strikingly in favour of the success of the Dover methods, including that of the single bake where the main importance is placed on dough characteristics and loaf volume is not measured.

When the results are thus simply examined it seems difficult to maintain Geddes' statement that the Dover baking method is not in any way superior to the standard procedures used in America in classifying flours on a strength basis. Certainly such a statement cannot be made about the final Dover assessment, which is essentially the point in question. This is not only superior but markedly so.

It only remains to deal with a few points raised in the Geddes

discussion. As regards wheat testing, baking is not normally the method employed in the writer's (Kent-Jones) laboratory as for such work dough testing machines have been found more informative.

Attention has been drawn to the fact that a simple classification of the flours by protein content would also place them in fairly exact order of baking strength. This, however, might not be so with other samples as there are many types of flour and wheat known to be high in protein content but which bake poorly even with diastatic correction. The author, for example, has been working on new varieties of wheats from Kenya, some of which are very high in protein (14 to 18%), but many of them certainly cannot be classed as anything like strong.

The only point on which the writer feels a fair criticism can be made is Table XII which indicates that the Dover baking with the malt-phosphate-bromate procedure (No. 4) gives a better assessment than the normal Dover baking on the Winnipeg samples. On the

TABLE XVI

COMPARISON OF LOAF VOLUMES OBTAINED BY WINNIPEG AND DOVER USING THE BASIC AND THE MALT-PHOSPHATE-BROMATE (NO. 4) FORMULAE

	Winnipeg samples			
	Basic formula		Malt-phosphate-bromate (No. 4) formula	
Sample	Winnipeg	Dover	Winnipeg	Dover
	Cc.	*Cc.*	*Cc.*	*Cc.*
1	655	569	935	844
2	518	484	765	644
8	592	511	760	586
9	545	500	695	576
10	512	469	615	583
3	475	464	550	500
11	495	449	542	570
7	490	429	568	558
6	505	474	538	411
5	560	563	570	534
4	480	494	532	482
		Dover samples		
Z1/401	658	626	665	593
417	575	520	548	545
416	570	524	568	623
403	515	562	488	515
400	555	553	510	543
399	500	550	485	515
415	565	570	518	530
404	525	600	530	—
396	460	458	435	518
418	520	505	630	558
397	538	538	552	588
414	475	445	502	538
398	430	440	395	440

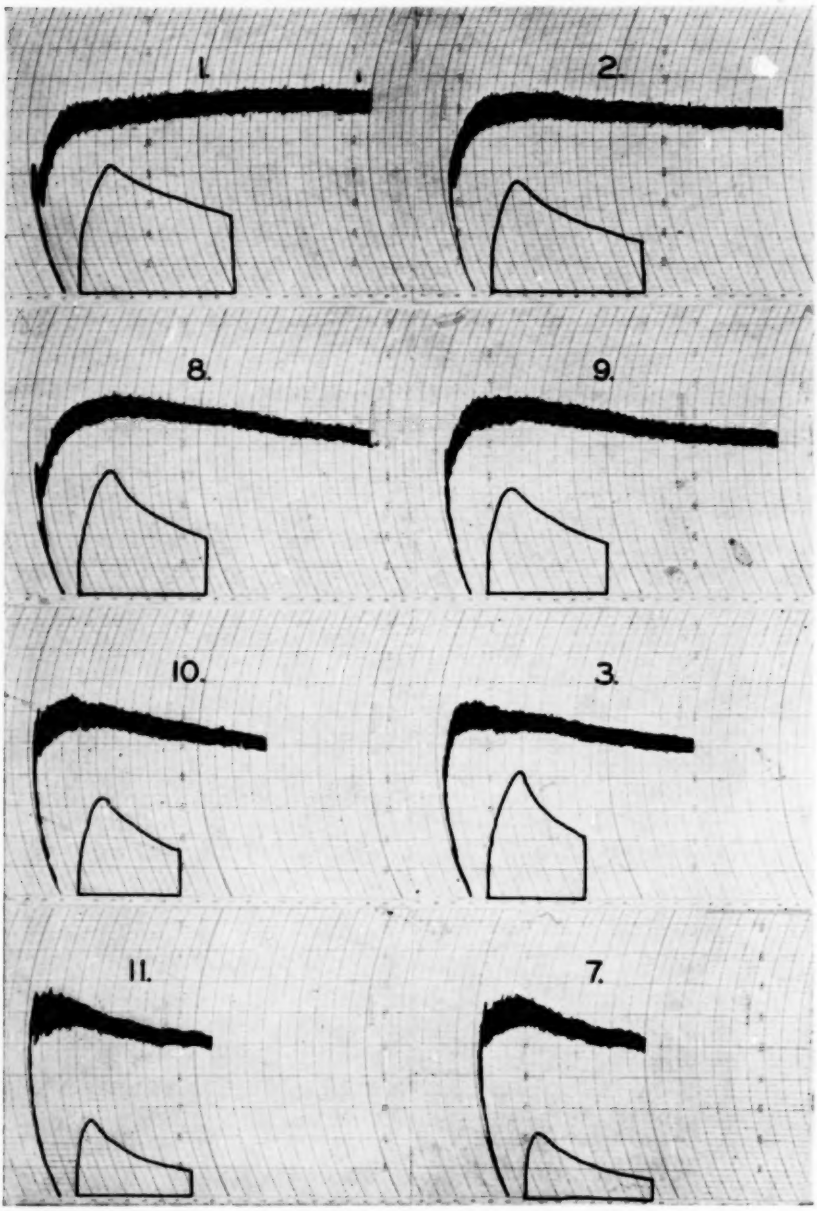

Fig. 1. Brabender Farinograph and corresponding Chopin Extensimeter curves for the first eight Winnipeg samples arranged in *a priori* order.

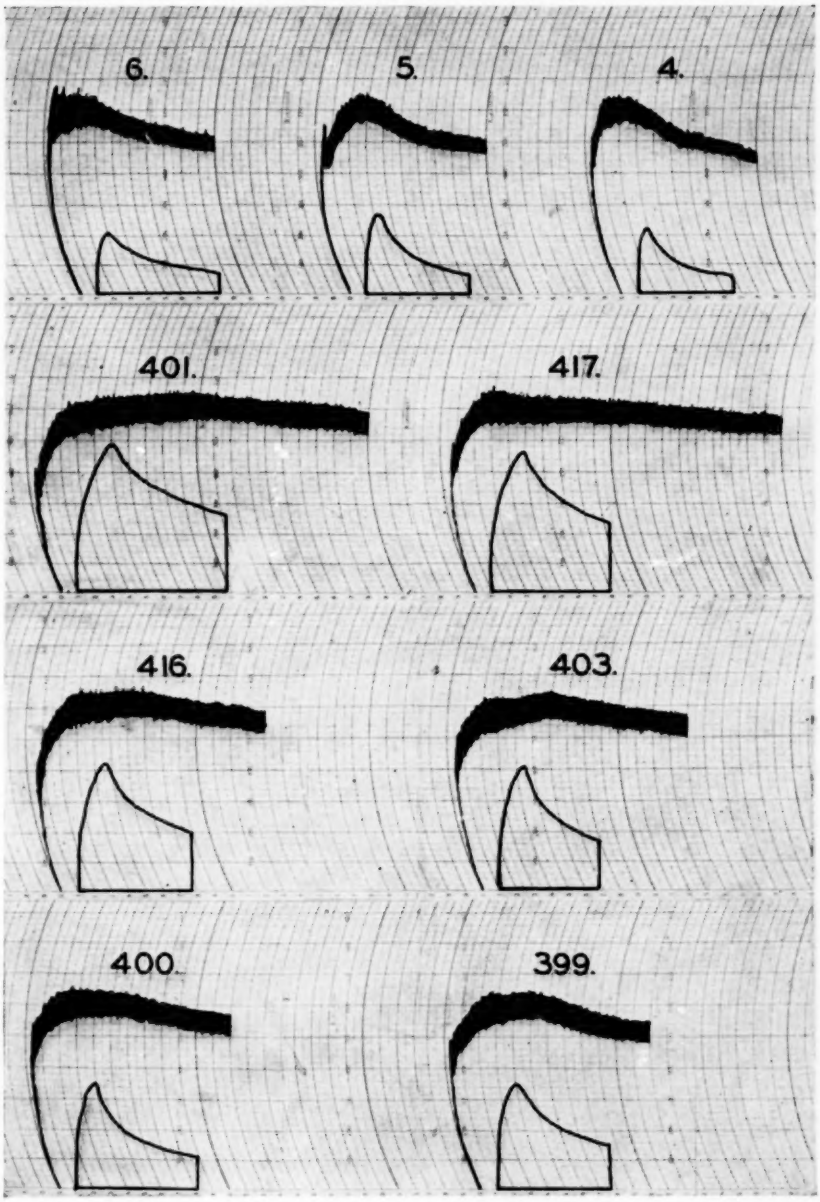

Fig. 2. Brabender Farinograph and corresponding Chopin Extensimeter curves for the last three Winnipeg and the first six Dover samples arranged in *a priori* order.

other hand, this is certainly not so with the Dover samples and it must be remembered that the criticism in the previous paper was not concerned with American flours but pointed out that the procedures were not suitable for commercial flours, from blended wheats milled under European conditions. Also the discrepancies in the loaf volumes with this method between the two laboratories is very serious and does not augur well for standardization on these lines. This is shown in Table XVI.

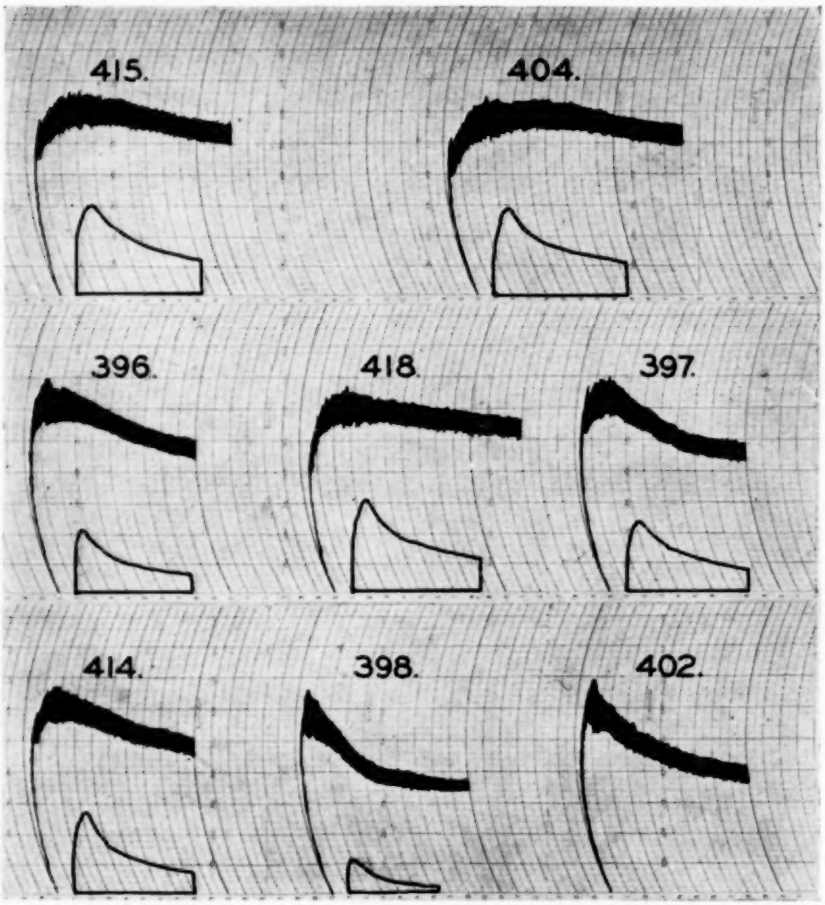

Fig. 3. Brabender Farinograph and corresponding Chopin Extensimeter curves for the last eight Dover samples arranged in *a priori* order.

To complete the paper the actual farinograms and Chopin curves of the various flours are given in Figures 1, 2, and 3.

To conclude, it seems to the writer that a strong case has been made out for dough testing instruments which, as has been pointed

out, are more amenable to standardization. Actually, both dough testing apparatus used have come out of the test extremely well, the Brabender Farinograph being better on the Winnipeg samples and the Chopin Extensimeter on the Dover samples.

It is, therefore, suggested that the general observations made in the writer's earlier paper (Kent-Jones, 1934) are definitely justified and confirmed. If this somewhat lengthy and difficult collaboration, therefore, results in progress in standardization along sound lines, it will have been well worth the while.

Summary

This co-operative investigation was undertaken to determine whether the methods of testing the quality of flours in North America give as accurate information in distinguishing flours of varying strength as those advocated by Kent-Jones, who, when applying baking tests, favours judging the quality of the fermenting dough rather than the volume of the finished loaf. Flour samples were exchanged by both investigators, so that each retained one set, the origin and composition of which were known, and received a similar set of which he was in complete ignorance regarding this information. After submitting the flours to his own methods of analysis in his own laboratory, each investigator undertook to classify each set of flours in order of descending quality and also to prepare a discussion of the complete data.

The flours were submitted to protein, ash, and diastatic activity determinations in both laboratories. The Winnipeg laboratory conducted baking tests by the Standard A. A. C. C. baking test and eighteen supplementary procedures, six of which were selected in arriving at a final classification. The Dover laboratory conducted two series of baking tests: the regular Dover baking test, the malt-phosphate-bromate American supplementary test, and also ran Brabender Farinograph and Chopin Extensimeter curves, the final classification being based on the mean placings by the Dover baking test and the two dough measuring instruments.

The results of the protein, ash, and diastatic activity determinations obtained by the two laboratories were mainly in close agreement but the strength classifications of the flours were widely at variance.

Geddes employed three standards for judging the classification of the flours: (*a*) the *a priori* order based on a knowledge of the composition of the flours supplied by each investigator, (*b*) the results of the Canadian and English baking tests for the Winnipeg and Dover samples respectively, and (*c*) the Brabender Farinograph.

On the *a priori* basis, Kent-Jones' final classification correctly placed five of the eleven Winnipeg samples and ten of the fourteen

Dover samples, while Geddes correctly placed six of the Winnipeg and three of the Dover samples. When comparisons were made between the results of baking tests only, Kent-Jones correctly placed eleven and Geddes nine of the twenty-five samples, the respective "misplacing figures," which are based on incorrect placings, being 27 and 34. The Brabender Farinograph accurately placed seventeen samples and the Chopin Extensimeter fifteen.

Applying the respective baking tests as the standards for classification, the Winnipeg laboratory, the Kent-Jones' final classification, and the Brabender Farinograph each placed thirteen samples correctly and the Chopin Extensimeter eleven, with misplacing figures of 32, 17, 24 and 22, respectively. By his baking test, Kent-Jones placed fifteen samples correctly with a misplacing figure of 20, the larger number of Dover samples giving him the benefit of three additional placings.

Employing the Brabender Farinograph as the standard, of the twenty-five samples studied, the English and Canadian baking methods successfully classified eight of the twenty-five samples with misplacing figures of 39 and 35 respectively.

With the *a priori* placings as a standard, it was noteworthy that each investigator was more successful in placing the flours with which he is accustomed to working, than with those of unknown origin and composition. On the other hand, the Brabender Farinograph and Chopin Extensimeter gave fairly satisfactory results with both sets of samples, so that the Dover final classification which is based on the mean placing by the Dover baking test and these dough measuring instruments, is much more satisfactory on the series as a whole than the Winnipeg classification, which is based solely on baking tests.

The *a priori* rating of the flours, particularly of the Winnipeg samples, closely followed their protein content and it was particularly striking that the physical methods of dough testing classified the samples essentially in the order of their protein content, the rank order correlations between the placings by protein content and Brabender Farinograph being + .98 and + .86 for the Winnipeg and Dover samples respectively.

Kent-Jones has emphasized that the respective merits of the two systems of evaluating flour properties should be the placing by Winnipeg of the unknown Dover samples by selected American baking methods and the placing by the combined Dover methods of the unknown Winnipeg samples, using in each case the accepted *a priori* classification. Out of fourteen samples, Winnipeg placed three correctly with a misplacing figure of 26. Out of eleven samples Dover placed five correctly with a misplacing figure of 10. If the revised

a priori standard is taken, Winnipeg placed four out of fourteen correctly with a misplacing figure of 22 and Dover nine out of eleven correctly with a misplacing figure of 4.

Kent-Jones has also emphasized that another useful method of comparing the two methods might be the placings of the total samples, again using the *a priori* and revised *a priori* standard. In this case Winnipeg placed nine correctly out of twenty-five (*a priori* standard) with a misplacing figure of 34 and Dover fifteen correctly with a misplacing figure of 14. In the case of the standard being the revised *a priori*, Winnipeg placed nine correctly with a misplacing figure of 32 and Dover twenty-one correctly with a misplacing figure of 6.

The Dover baking alone with the *a priori* standard placed eleven correctly with a misplacing figure of 27 and with the revised *a priori* it placed thirteen correctly with a misplacing figure of 21.

The Dover baking method alone on the unknown Winnipeg flours placed three out of the eleven samples correctly with a misplacing figure of 20, using the *a priori* standard (a large percentage of the error being due to the abnormality of sample No. 3, which was reported upon) and three correctly with the revised *a priori* standard with a misplacing figure of 14.

From the analysis of the data, employing the three standards of reference, Geddes concluded that there is little to choose between the English and Canadian baking methods in evaluating the series as a whole. The success of each investigator in placing the flours with which he is accustomed to deal indicates that the respective methods are quite dependable for the purpose for which they have been designed. It is noteworthy, for example, that Kent-Jones was more successful in classifying the Winnipeg samples by applying one of the Canadian baking tests, which on the other hand gave less satisfactory results than his regular baking test on the Dover samples.

Although the baking test advocated by Kent-Jones appears to be rapid, Geddes pointed out that it requires the services of a highly skilled expert baker whose reports are based entirely upon personal opinion and does not provide permanent quantitative data for future reference.

Using his standards of reference, Kent-Jones concludes that the combined Dover assessment is markedly superior to the six baking methods selected out of the eighteen methods, while even the simple Dover baking is superior to the selected and adopted standard methods.

Kent-Jones also states that his collaboration emphasizes his suggestion that there is more hope of standardization along the lines of mechanical dough measurements than in standardizing the baking test on the lines of the American standard baking test.

Acknowledgments

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Expression of appreciation is also tendered T. R. Aitken by the junior author, for helpful and constructive suggestions, and for his assistance in carrying out the work and in the preparation of the report.

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THE ENZYMES OF FLOUR IN RELATION TO YEAST FERMENTATION [1]

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Part I

INTRODUCTION

The enzymes of flour as related to yeast fermentation in the dough is a subject which has concerned our laboratory greatly during the last six or seven years. We have regarded the flour and the yeast as two mechanisms each with its own rate of reaction, one being dependent on the other within certain limits. In the case of flour, the saccharogenic activity is governed by starch susceptibility, granulation, and by the enzyme content. Frequently, however, the enzymes are not present in sufficient amount or the starch susceptibility is insufficient to supply the yeast with sugar in a normal fermentation. The colloidal properties of the dough, such as the ability of gluten to produce well piled loaves, are not involved directly in this conception. Fermentation tolerance and diastatic deficiency constitute definite categories according to this point of view.

Systems involving a number of successive enzyme reactions are common in nature, and usually result in a complexity difficult indeed to unravel. These in the dough are probably illustrative of many, the mechanism of which is by no means so clearly understood. Here the principle net change is a transformation of starch and sugars to the leavening gas, carbon dioxide, along with alcohol and some acids and flavoring substances. Although not yet wholly clear, the successive steps appear to be somewhat as given in Table I.

Each enzyme reaction has its own peculiarities as to optimum conditions, tenacity of substrate complex, and inhibition by end products, and thus change of velocity. Metabolic state of the yeast is also important. Is it any wonder that the rate of rise of the dough, itself changing constantly in H-ion activity, or that the evolution of CO_2, as a measure of the overall conversion, gives a complex, wavering curve, almost defying analysis? Investigations by James and Huber (1928), Kozmin (1931), and Larmour and Brockington (1932 and 1934) are enlightening in this connection. Yet under the relatively constant conditions in dough, certain phases are of sufficient simplicity to allow some interpretation and within limits, control. This is due to two

[1] Part I, paper read by Charles N. Frey at the meeting of the Association of Official Agricultural Chemists at Washington in 1933.

principles based on the mass action law which governs enzymic actions: (1) In the presence of an excess or constant amount of substrate, a small amount of enzyme will convert at a uniform rate proportional to the concentration of enzyme when the end product concentrations are also constant, while (2) with limited amount of substrate in reference to the concentration of enzyme, conversion approaches a limiting logarithmic form. The net result is represented by a complicated curve which may

TABLE I

Steps	Material (Substrate)	Acted upon by (Enzyme)	Source of enzyme	pH optimum	Relative thermolability	Principal product
1.	Native starch [1] of varying susceptibility	Alpha amylase, dextrinogen-amylase or liquefying enzyme	Flour, aulerone and germ cells	5.0 to 5.5	70–75° C.	Soluble starch, various dextrins and alpha maltose
2.	Soluble starch and dextrins	Beta amylase, saccharogen-amylase or saccharifying enzyme	Flour, principally germ cells	4.5 to 5.0	65–70° C.	Beta maltose
3.	Maltose, sucrose	Maltase,[2] invertase	Yeast cells	4.0 to 6.0	55–60° C.	d-glucose, invert sugar (monosaccharides)
4.	Certain monosaccharides, some dissaccharides	Zymase system	Yeast cells	4.0 to 6.0	55–60° C.	Carbon dioxide and alcohol

[1] A hemicellulose dissolving enzyme termed cytase has been hypothesized by Brown and Morris (1890), and by Gruess (1896) to explain the initial step in the saccharification of raw starch. Evidence for its existence is not yet positive. In this connection compare the "growth structure" theory of Katz and Derksen (1934), and the coordinate link-association hypothesis of Taylor (1935).

[2] Sandstedt and Blish (1934) have announced the discovery of a co-maltase like substance in flour. Genevois and Pavloff (1935) state that maltose in flour is fermentable only after the addition or in the presence of the *Z* factor of Euler and Larson (1934). The two may be related substances.

alternate from one extreme to the other, or pursue a variable intermediate course.

In order to appreciate better the significance of these successive steps in the saccharogenic-fermentation reaction as they apply in bread production, a review of the development of the concepts involved will be given.

Discovery and Early Developments [2]

That famous scientist, Kirchhoff, in 1815 reported that a crystallizable sugar could be obtained by the action of extracts of malted grains on starch. Almost simultaneously Nasse (1814) found that

[2] Compare the investigations reported by Rumsey (1922) and Collatz (1922).

starch separated from living plants which have not been previously boiled could effect its own transformation to sugar. The nature of this phenomenon remained largely a mystery until the work of Payen and Persoz (1833) and collaborators showed that it was due to some substance specifically associated with the extract. To them is due the name diastase (Greek—dia, apart, + histēmi, stand). Still the exact nature of the process was incorrectly conceived,—glucose being considered the final product. Dubrunfaut (1847) and still later O'Sullivan (1872) as well as Schulze (1874) proved the principal product to be a disaccharide, maltose, together with higher polysaccharides. These discoveries were the subject of an enormous amount of work beginning shortly after Trommer's (1841) introduction of the use of alkaline copper solutions for analytical tests. Kjeldahl (1876–1882) enunciated his "law of proportionality" of uniform rate to enzyme content (up to 40% conversion) and this was followed by Roberts' (1881) iodine method and Lintner's (1886) reducing sugar method for the estimation of the strength of diastatic preparations. It is doubtful if either Lintner or Roberts recognized at the time that they were probably measuring two different, but related, activities.

Dual Nature of Diastase

Maercker (1878), in order to explain differences in the temperature coefficients and distribution of the products, was led to suggest that there were really two enzymes. This became more and more apparent as investigations by Brown and Heron (1879), Brown and Morris (1885), Effront (1885 and 1887), Gruess (1897), Brown and Glendenning (1902), Baker and Hulton (1908), Ford and Guthrie (1908a), and others, were carried out. It became apparent that the diastatic activity of ungerminated cereals, "resting barley," was largely due to the saccharifying component. The liquefying component was developed principally only during the sprouting of the grain. The extraction of the enzyme was found to be greatly affected by various inorganic salts as well as proteolytic digestion during the extraction. Meanwhile the identity of the final and intermediate products of the reaction were the cause of much discussion.

It is interesting to note the difficulties which attended those investigations because of the lack of the concepts regarding pH and buffer action provided by Sorensen (1909), (*cf.* Duggan (1886)). Many disagreements and failures to check contemporaries' work were due to the failure to recognize this factor. For example, Maquenne and Roux (1906) specify that ". . . to obtain rapid saccharification it is necessary to have an amount of acid (sulfuric) equal to ⅓ to ⅔ of that which would be required for complete neutralization" (to helianthine).

Fernbach (1900) found that acid phosphate produced remarkable activation of diastase. Gruess (1896), Mohr (1902), Effront (1904), Petit (1904), and others, studied the "activation" produced by small amounts of asparagin, lactic acid, acid phosphates, *etc.* Ford (1904) and Ford and Guthrie (1906) correctly recognized that these supposed activities were in general due to acidity changes. The application of Sorensen's (1909) principles removed an exceedingly troublesome and variable factor from this field of investigation. However, further to complicate the situation Mangles and Martin (1935) have recently offered data on the specific effect of different buffers on diastatic activity.

Since the subsequent development of diastatic activity with reference to bread production leads in a different direction, it is needless to review the multitudinous variations in the fundamental methods of Roberts and Lintner (*loc. cit.*), or the success which has attended the efforts to separate the two components in relatively pure form. Reviews of these phases of the subject are given by Chrzaszcz (1931), Andrews and Bailey (1934), Read and Haas (1934), Green (1934), and Mangels and Martin (1935). It has been shown by many investigators that flour is plentifully supplied with saccharifying enzyme but is often deficient in the liquefying component. It may eventually be found that a suitable index of liquefying activity will be of even greater value than the autolytic determination has been.

Diastatic Activity as a Factor in Bread Production

The bitter disputes between the schools of Pasteur and Liebig over the function of micro-organisms in chemical processes and the long struggle leading to the final establishment of the vitalistic theory of fermentation are well known to biochemists and have been reviewed elsewhere (see Frey, 1930). Until the correct theory of pannary fermentation was accepted but little progress could be made. Consider, for example, the hypothesis of Chicandard (1883) as summarized by Jago (1895): "The fermentation of bread does not consist in the hydrolysis of starch, followed by alcoholic fermentation, and is not determined by *Saccharomyces*, but is a result of the solution and after peptonization of the gluten. . . ." Marcano (1883) and Boutroux (1891) were probably the first to recognize the significance of Pasteur's results on fermentation with respect to bread production. It was then but a step to realize that diastatic activity should be a factor in bread-making (see Jago, 1895). Reychler (1889) prepared an active diastatic preparation from gluten. Parenti (1903) observed that the sugar content of dough decreased during fermentation. Nevertheless its full significance was not recognized until the work of Wood (1907) and contemporaries.

Wood found that the sugar content of a yeast-free dough increased with the time. He devised a fermentation method for estimating the total gas formed and logically converted his gas volumes into percent sugar. With noteworthy exceptions it was observed that the quality of the bread produced was often related to the potential gassing power of the flour. Liebig (1909) working independently at about the same time confirmed Wood's conclusions and found sucrose preexistent in the flour. He isolated maltose as a product of diastatic activity in the dough and realized that the activity of the yeast was such that the sugar left at proof time could approach dangerously low values. About 1907, Alway and Hartzell (1910) began their investigations of the relation between gassing power and baking quality. They used a flour suspension with 12.5% yeast and observed the diminution in fermentation rate caused by diastatic limitations. However, no consistent relation between baking strength and gassing power was found. Ford and Guthrie (1908) determined the Lintner values of flours, but could not definitely relate their figures to the baking results.

Simultaneously, investigations were undertaken to increase the baking value by the use of diastatic supplements. Humphries and Biffin (1907), Newman and Salecker (1908), Baker and Hulton (1908a), Humphries and Simpson (1909), and Galli and Gerardini (1912) added various diastatic enzyme concentrates to the dough and in the majority of cases observed an improvement. Sugar formation and gassing power were increased. In some cases the improvement was not thought to be due to diastases added with the concentrate, but rather to accompanying proteases. Suitable quantitative methods were lacking; observations were in most cases qualitative in nature. *Diastase content* as measured by variations of Lintner's or Roberts' method was used, and was found to give little or no information as to the results to be expected in the dough. A clue to a more lucrative line of investigation is given by Humphries and Simpson (1909), but was apparently not followed up. These investigators presented evidence to indicate that it is not the amount of the diastatic enzymes themselves which was important, but the rate at which the starch granules are attacked. They foreshadowed the development of the autolytic method.

After the World War the subject was again opened. Meanwhile the results of Jessen-Hansen (1911) on the effect of pH as a factor in bread production had appeared, and this aspect of the system was a primary consideration. Martin (1920) concluded that high gassing power was essential in strong flours, but that a deficiency could be rectified by the addition of supplements. Weaver and Wood (1920), Weaver and Goldtrap (1922), and Buchanan and Naudain (1923) came

to much the same conclusion. It was gradually recognized that the effect of pH was not so much on the inherent characteristics of the gluten itself as on the enzymes. Jørgensen (1933) has reopened this question and finds some effect, but he proofed his dough to constant time, not constant volume. Kozmin (1933) has indicated a method for the control of excessive diastatic activity by pH variation. Further progress in the relation of diastatic activity to bread production awaited the development of an analytical index more closely related to the actual conditions existing in the dough.[3]

Autolytic Diastatic Activity—The Important Factor

This index to measure autolytic diastatic activity was provided by Rumsey (1922). Swanson and Calvin (1913) had investigated the formation of sugars in flour suspensions at normal dough temperatures. (Jago and Jago (1911) had performed the autolysis at 60° C.) This method appealed to Rumsey as most closely approaching actual dough fermentation conditions. He devised suitable methods for clarification of the suspension and determination of the reducing sugars. He established a unit of autolytic diastatic activity; amount of maltose formed during the first hour of diastasis of a flour suspension. Rumsey concluded that if all other factors were the same, the baking strength should follow the degree of diastatic activity.

The Rumsey method was criticized because of its lack of pH control. Sorensen (1924) recommended determining the activity at a sufficient number of points to define the *rate of change* of activity with changing pH. Realizing the value of such a procedure Grewe and Bailey (1927) determined the activity at two different points, and found variable rates of increase, which might be interpreted in terms of starch susceptibility.

Rumsey's original method has been subjected to numerous modifications. Kent-Jones and Saxby (1929) applied other methods of sugar analysis to the determination of the maltose produced, and expressed the results in "percent units" instead of the rather inconvenient designation "milligrams of maltose per 10 g. of flour." Malloch (1929), believing the suggestion of Sorensen (1924) to be impractical, adjusted all flours to the same pH. The remarks of Hartkoff (Proceedings 18th annual meeting of A. A. C. C., page 27 *vide infra*) apply here with equal force. Pelshenke (1931), Briggs (1933), and Gore (1933) have proposed polarimetric methods for indicating the amount of reducing sugars formed while Molin (1934) used the refractometer. Blish, Sandstedt, and Astelford (1932), Blish and Sandstedt (1933), subjected the method to a very critical and comprehensive study, determined the

[3] Even now, frequently investigators present evidence to show the inapplicability of Lintner values to the problems of dough fermentation.

sources of various errors, and developed it to a relatively high degree of accuracy. Czyzewsky (1933), Tague (1928), as well as Geddes and Eva (1935) also made contributions.

Two (or More) Principal Factors in Autolysis

Mangels (1926a), using the Rumsey method to study the effect of certain environmental factors, presented evidence that the method measured the summation of the effects of diastase content and starch susceptibility. Alsberg (1926) recognized three factors: diastase content, injured granule content, and susceptibility of the uninjured granules.[4] He gives many references to previous investigators who have shown variations in susceptibility. Results of Brown and Heron (1879), Stone (1896), Humphries and Simpson (1909), Whymper (1909), Reichert (1913) and many others indicated that variations in *raw*, not fully gelatinized, starch might be expected.

Malloch (1929) in investigating the nature of autolytic activity recognized the importance of the kind and amount of the flour diastase, but, preferring to study the resistance of the starch, developed a method of preparing diastase-free flour and tested the resistance by the use of a uniform sample of takadiastase. Based on Osterhout's principle, he determined the time required for the conversion of a given (small) amount of the starch. The unit is one of resistance, not susceptibility, expressed as the reciprocal $\times 10^4$ of the theoretical amount of maltose produced in one hour. (See also Hopf (1932), Kuhl (1933), and Mangels (1934).[5])

Sherwood and Bailey (1926) state that a flour with a Rumsey value of 200 units usually performs satisfactorily. Merritt, Blish, and Sandstedt (1932) recommend the use of 5% sugar in the basic procedure for experimentally milled flour. Bohn and Machon (1933) with reference to whole wheat flours state ". . . if a deficiency in gassing strength is suspected additional fermentable carbohydrates should be added." Kent-Jones (1924) recommends a maltose number of 1.5 for European conditions. It may appear strange, in view of the relatively high degree of accuracy to which this and various gassing-power methods have been developed, that no other attempts have been made to relate the results of diastatic activity tests to the *amount* of diastatic supplement *to be added to the formula for that particular flour* under test in order to eliminate diastatic activity as a factor in the baking test and thus allow the factor of strength to be determined. It seems to be due to the concept of the fixed type procedure which has been advocated

[4] Steller, Markley and Bailey (1935) present evidence for still another factor.

[5] Landis (1935) has recently defined a measure of susceptibility based on measurements of reaction velocity and liquefying enzyme concentration, l: $R = \left(\frac{\partial^2 S}{\partial \log l \, \partial \log t}\right)$ = "Susceptibility constant," where S and t are sugar concentration in the dough or suspension and time, respectively.

during the past decade. Evidence to show the inadequacy of such a concept in the general testing of flour [6] has become overwhelming in recent years, and will be presented later in this paper.

Autolytic Activity Principally an Environmental Factor

The fact that environmental conditions such as rainfall, locality, and type of harvest are important factors determining the diastatic activity of flours was shown by Mangels (1926a), Johnson and Whitcomb (1927), Mangels and Stoa (1928), Bracken and Bailey (1928), and others. Moreover this factor is profoundly influenced by milling procedure, as indicated by Alsberg and Griffing (1925), Shollenberger and Coleman (1926), van der Lee (1928), Johnson (1930), Pasco, Gortner, and Sherwood (1930), and Karacsonyi and Bailey (1930). In addition, it has become apparent, since the application of the Rumsey method to the measurement of diastatic activity, that the inability of the earlier investigators (Wood (1907) and contemporaries, Martin (1920), Weaver and Goldtrap (1922), etc.) to obtain high correlations between diastatic activity and baking quality was not a fault of their technique and theoretical knowledge but an impossibility inherent in the nature of the flour complex when baked under fixed conditions. Collatz and Racke (1925) obtained but slight correlation between loaf volume and diastatic activity. Pasco, Gortner, and Sherwood (1930) could detect no such correlation. Blish, Sandstedt, and Platenius (1929) were able to obtain significant correlations only between diastatic activity and crust color. The results of Swanson and Kroeker (1932) point in the same direction. Further, since 1907 it has been apparent that deficiencies in diastatic activity could be easily controlled in the formula by the addition of various diastatic supplements (Wood (1907), Swanson, Fitz, and Willard (1915), Olson (1917), Weaver and Wood (1920), Collatz and Racke (1925), Markley and Bailey (1931), Harris (1932), Bruère (1932), Bruère and Chevalier (1933)).

From all these data the conclusion is inescapable that diastatic activity is not a factor primarily inherent in the variety of wheat [7] and only serves to obscure the inherent properties related to strength with any fixed type baking procedure. This has been definitely pointed out by Kent-Jones (1924), Fisher and Halton (1929), and Jørgensen (1931); see also the work of Elion (1931). Blish and Hughes (1932) also

[6] In checking laboratory technique on a single flour the procedure must, of course, be fixed between laboratories.

[7] Markley and Bailey (1934), and Steller, Markley, and Bailey (1935) by statistical analysis and rod row trials have found that there are certain inherited tendencies in this respect. Coleman, Snider, and Dixon (1934) confirm this to some extent, particularly for the major classes of wheat, but they also state that the diastatic activity of those wheats grown on the same soil series and under the same climatic conditions did not differ by more than 10%. Moreover, Swanson (1935) in a comprehensive investigation of the effect of milling conditions concluded that large variations in the same variety are induced in response to environment. Thus we must still conclude that diastatic activity is primarily an environmental factor, and only secondarily influenced in magnitude by inherited characteristics.

distinctly recognize the independence of the gassing and gluten factors.[8] Diastatic activity thus takes its place as an essentially environmental factor under the direct control of the technician along with absorption. Hence the "Short Method" modification of standard conditions advocated by Merritt, Blish, and Sandstedt (1932) with no initial addition of sugar and no fixed restrictions on diastatic supplement or absorption, represents a satisfactory starting point for test baking.

Diastatic Activity as a Dynamic Process

The investigators above mentioned with but few exceptions have been content with a single figure or index with which to describe the activity observed, although recognizing it as a dynamic process (see Berliner and Rüter, 1928). They have shown that the sugar level in doughs and suspensions is conditioned by a number of factors, chief of which are, the initial sugar content, i (see Dangoumau (1932), Blish, Sandstedt, and Astelford (1932), Guillement and Schnell (1934)); the diastatic content, d; starch susceptibility, R; H-ion concentration, pH (see Olsen and Fine (1924); end product concentration, e; temperature, T; and time, t. Of these i, d, and R may be considered constants for any one flour. In the dough, however, pH and time are continually changing; hence the potential sugar level of the dough changes, and it may be expected that the nature of this change will vary from flour to flour. Expressed mathematically in the broadest manner (Landis, 1934):

$$S_p = F(i, d, R, \text{pH}, t, T, e, \cdots).$$

Considering only the simplest system, with all factors constant except S_p, e, and time (the case in buffered flour suspensions), the relation between these two variables is not linear. When yeast is added the pH becomes an additional variable and e also changes in a complex manner. Thus diastasis in practical bread production is a dynamic variable factor, changing from flour to flour and formula to formula. It is hardly possible to obtain more than a qualitative picture from any single figure index of activity.

Nevertheless, as previously intimated, conditions in the dough are sufficiently constant compared to the wide variations found in flours and formulas that, lumping several factors into one, this process may be followed within certain limits of accuracy—limits which are, perhaps, sufficiently close for our present requirements. The potential sugar concentration of flour-water-yeast mixtures under various conditions has been studied by Landis (1934). The sugar concentration of a yeast-free dough as a function of time can be simply expressed

[8] The recent publications of Larmour and Brockington (1934) and Geddes and McCalla (1934) also distinguish these factors.

by a logarithmic equation. When yeast is present an initial logarithmic phase is followed by a linear one, after which the logarithmic change is resumed. As the amount of yeast is increased the duration of the linear portion of the curve becomes successively shorter, until with a relatively large excess of yeast it becomes too short to observe. In addition, the actual level, particularly in the earlier stages of the fermentation, increases with each increment in yeast percentage. However, for yeast percentages of 2 or more the greatest deviation from calculated values (*vide infra*), in the case of the patent flour cited (it is less for lower grade flours), is about 0.7% sugar, occurring at 2 hours, while later in the ranges at which sugar exhaustion is likely to occur, the discrepancy is much less—approximately 0.2% sugar.[9] The difference between the potential sugar level of a yeast-free dough and a dough containing 1% yeast or over may be as great as 1.5% or more. Hence, the maximum limits of error for potential sugar levels in fermenting doughs containing more than 2% yeast, as determined by any fermentation method which defines the general course of diastasis throughout normal fermentation times, should be in the neighborhood of 0.7%. It is also important to notice that at the *time of sugar exhaustion*, the critical point referred to below, this maximum deviation is much less.[9]

Neglecting for the present, then, the linear phase of the reaction, the potential sugar level in a fermenting dough containing more than 2% yeast may conveniently be expressed within the limits of error defined above as follows:

$$S_p = \frac{s}{\log 2} \log t + p,$$

where p is the sugar level at one hour and s is the additional sugar formed during the second hour. This equation is more easily solved from a nomograph (*cf.* Landis, 1934). A ruler placed across the chart will indicate the sugar level at any time. It is necessary to have two constants, however, in order to locate the position of the ruler. These, p and s, appearing in the above equation have been found to be characteristic for the flour *when determined under conditions at least approximating those obtained in the dough.* Therefore, they have tentatively been designated the *primary* and *secondary* saccharogenic (autolytic diastatic activity) values of the flour. They are wholly arbitrary, convenient constants, which contain the effect of several factors. From them or other similar constants, the dynamic course of the diastasis in fermenting doughs may be estimated within limits as previously indicated.

[9] Samdstedt (1934) has shown close agreement between the total sugar concentration of suitably buffered flour suspensions and the potential sugar level of fermenting 3% yeast doughs at the 4-hour period.

Comparing this simplified equation with that first presented indicating all the variables it is apparent that the initial sugar content, i, has been included in the value, p. It seems probable that the factor of diastase content, d, is also included in p. The susceptibility of the native starch, R, is thought to be the major factor in determining the secondary saccharogenic value, s. T is maintained constant. The variations of pH and e have not been eliminated but *have been limited*, by confining our observations to fermenting doughs or suspensions with a yeast content of roughly greater than 2%. Without doubt the limits of accuracy which have been set up for the simplified equation are partly conditioned by the rate of pH change and end product concentration, e. As will be seen in the next section, these are conditioned to a large extent by the fermentation, hence, by limiting the variations in these factors, corresponding limits in the errors of the calculation of the actual potential sugar level at any time may be established.

Yeast Fermentation in the Dough as a Dynamic Process

Yeast fermentation or rate of gas production in doughs as it changes with time seems first to have been studied quantitatively by Bailey and Johnson (1924), (see Bailey (1916), and Bailey and Weigley (1922)). Since then many investigations, almost too numerous to mention, have been made using the principles developed by these workers. Various factors have been found to influence the rate of fermentation, but the general form of the dynamic process remains the same. After mixing there is a gradual acceleration in rate, until a maximum is reached. This maximum is essentially maintained, usually dropping slightly, *until the concentration of fermentable sugars is reduced to a low value*, when a pronounced drop in rate occurs. This is tentatively termed the critical point. As will be indicated in a later section, the rate of fermentation subsequent to this critical point is conditioned by the rate of diastatic action. Unfortunately Bailey and collaborators seldom carried their fermentation to this point (it is just indicated in a chart published by Karacsonyi and Bailey (1930)), but it is shown splendidly in the curves of Geddes and Winkler (1930) and of Larmour and Brockington (1934). Limiting our considerations now to that part of the process occurring *before* the critical point is reached, a simplified expression for the amount of sugar fermented (as calculated from the expansion produced, *cf.* Schultz and Kirby (1933)) at any time after a certain point may be obtained. In Figure 1 the equation of the line tangent to that part of the curve which is essentially linear is:

$$S_f = r_m(t - l_v), \qquad S_f < 8 - 9\%,^{10}$$

[10] Depending upon conditions this is the approximate limit of applicability of the simplified equation.

where S_f is the amount of sugar fermented (expressed as percent), r_m the *average* maximum fermentation rate in percent sugar per hour, and l_v the intercept of the tangent on the time axis, in hours. This latter quantity, l_v, has been termed the ***virtual lag period***, to distinguish it from the actual lag period, *i.e.*, the length of time elapsing after mixing until the average maximum fermentation rate is reached. This equation gives the amount of sugar fermented at any time between the end of the actual lag period (roughly twice the virtual lag period) and the critical point previously defined, for most hard wheat patent or straight grade flours. The constants r_m and l_v are deter-

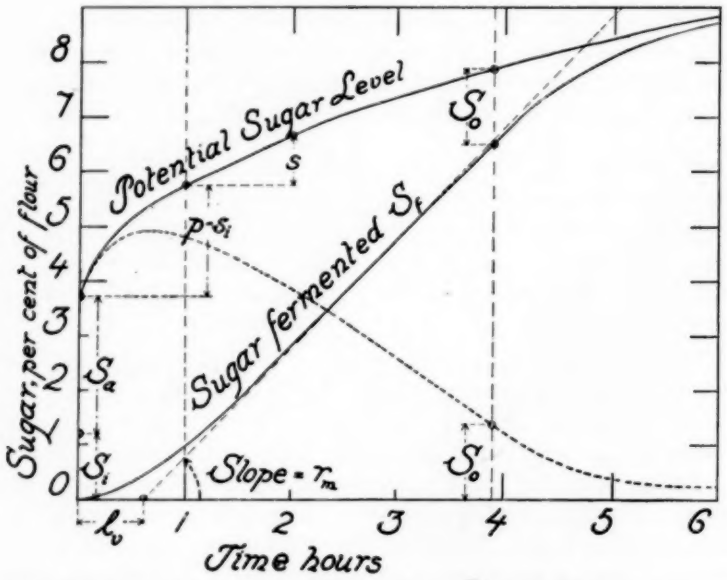

Fig. 1. The relation between fermentation and saccharogenesis in doughs. Represents the relations with a flour ($p = 3.1$, $s = 0.9$) in which the diastatic capacity might be considered barely sufficient for present conditions. S_i, initial sugar content. S_a, added sugar. p, s, saccharogenic values of the flour. l_v, virtual lag period. r_m, average maximum fermentation rate in the dough, % sugar per hour. S_o, oven point sugar level. The dotted curve indicates the actual sugar level in the dough (*cf.* Collatz and Racke, 1925). The diagram is intended to represent Standard A. A. C. C. Baking Test conditions.

mined by the amount, kind and uniformity of the yeast used, and by the temperature. Certain dough ingredients, such as dry skim-milk, also affect the values of these constants, but again, imposing limitations in the range of these variables, corresponding limits of error may be established for the amount of sugar fermented. In general it has been found that with uniform yeast these limits are now considerably smaller than those determined for the diastatic process in the dough, hence the two may be compared with the expectation that the combined limits of error will be less than twice that of the latter.

Interaction of Diastatic and Fermentation Processes

Comparing the potential sugar level, S_p, with the amount of sugar fermented, S_f, it is apparent that the former increases rapidly at the start, then the rate of production diminishes, while the reverse is true of the latter. In effect the diastatic process builds up a reserve supply of fermentable sugar, which is rapidly depleted as the fermentation reaches its maximum rate, *provided*, however, that the rate of diastasis is not above a certain range of values. The relationship is complicated by the fact that one process changes logarithmically, the other linearly, with the time, thus the two actions cannot proceed at equivalent rates. Under normal conditions, unless an extremely small amount of yeast is used with a flour of excessively high diastatic capacity, the two curves are bound to cross (Figure 1). The time after mixing and the potential sugar concentration at which this occurs has been termed the critical point, and a determination of this value, conveniently made in any baking laboratory or bake-shop serves as a technological method for the determination of the adequacy of the diastatic capacity (see Frey, 1933).

The fermentation reacts on the diastatic process in a remarkable manner. The greatly increased diastasis in fermenting doughs over yeast-free doughs has been previously mentioned. Moreover, for a time there is a uniform increase in potential sugar level. Rumsey (1922) and others have shown that diastatic activity increases greatly as the pH drops from 6 to 5. Halton and Fisher (1932) have followed the change in pH during dough fermentation and find it to decrease in a regular manner. Inspection of the results of these two investigators shows that both changes are approximately logarithmic in nature. It is highly probable, therefore, that this linear phase of the diastasis is due to the compensation of normal decrease in activity at constant pH (logarithmic) by decrease in pH.

Another effect of fermentation is decrease in the concentration of end products. This probably exerts little effect in the early stages of the reaction, but may be a factor contributing to the generally higher levels of fermenting doughs. It has been suggested that liberation of enzyme through proteolysis may be a factor. Should such be the case, it is more likely due to an increase in the activity of the feeble proteases of the flour caused by change in pH rather than to any direct effect of the yeast. The magnitude of the effects of both these factors is as yet but dimly perceived, and clarification awaits the development of more accurate methods.

The diastatic process also conditions the fermentation, but, as far as can be determined at present, in only one way. This usually results, however, in a sudden and drastic effect. When the actual

sugar level is reduced to a certain threshold value (approximately 0.5% sugar as a disaccharide for 3% yeast, according to Geddes and Winkler, 1930), the rate of fermentation is limited by and becomes equal to the diastatic rate. If this is low, the dough becomes "dead" in no uncertain terms, and even a relatively high secondary value may give but a slow, gradual rise. As we shall see, this effect has been a factor in many baking studies.

Summary

Dough fermentation is conditioned by two independent enzymic systems: the diastatic enzymes of flour and the yeast enzymes, invertase, maltase and the zymase system.

The concepts regarding diastatic activity with reference particularly to bread production have progressed through six important stages:

1. Discovery of enzymic action by Kirchhoff (1815).
2. Recognition of the dual nature of diastase by Maercker (1878).
3. Perception of the importance of diastatic activity in bread production by Wood (1907), Humphries and Biffin (1907) and contemporaries.
4. Establishment by Rumsey (1922) of the fact that it is autolytic diastatic activity (saccharogenic activity) which is the important factor in baking chemistry.
5. Recognition of the dual nature of autolysis by Stone (1896), Whymper (1909), Reichert (1913), and its establishment by Mangels and Stoa (1928) and Alsberg (1926).
6. Recognition of saccharogenic activity as primarily an environmental factor under direct control of the baker by Kent-Jones (1924), Fisher and Halton (1929), Jørgensen (1931), Swanson and Kroeker (1932), and others.

Diastasis in doughs within certain limitations may be designated by a logarithmic function of the time.

Fermentation in doughs for normal fermentation times can be expressed essentially as a linear function of the time.

Hence diastasis may and frequently does become the limiting factor in normal fermentation.

Methods of satisfactorily correlating diastatic activity to fermentation will be presented subsequently.

Part II

Fitting Diastatic Activity and the Fermentation Process [11]

It has been indicated that diastatic activity and fermentation in doughs were susceptible to quantitative determination and calculation, within limits. Hence it should be possible to relate and to adjust diastatic capacity to the fermentation requirements of the baking conditions.[12]

In the past, diastatic capacity has usually been roughly fitted to the fermentation requirements after the damage has been done, a batch of bread spoiled, or a pale, ragged loaf of nondescript characteristics obtained. The art of the expert baker has been invoked to determine the cause of the failure and to prescribe approximately the method to be used in supplementing the diastatic activity. It was then usually necessary to re-bake the test loaf or batch according to these prescriptions (*cf.* Bayfield and Shiple, 1933). While a rough idea of the diastatic capacity of a flour can be obtained from a suitable test bake without sugar, or with a limited amount of this ingredient, there are other simpler, more accurate and more reliable methods. The remarks of Mangels and Stoa (1928) with reference to the determination of color apply with particular force in this connection: "In our experience, however, the degree of pigmentation can be more satisfactorily determined by such tests as 'gasoline color value' than by scoring the loaf." Methods by which the diastatic capacity can be "more satisfactorily determined" are summarized below. Such a procedure will allow a logical correction of the ingredients to be made.

Variable Formula *vs.* Fixed Formula

That variations in formula are sometimes considered to be illogical seems strange indeed. The time since variations in absorption to suit the particular flour in question have been made is lost in antiquity (see Guthrie, 1896). Larmour (1929) states "In baking the Werner formula was used, with a procedure fixed in every respect except absorption. With flours varying from 57% to 75% absorption . . . it is unwise to attempt a fixed absorption." Geddes and Goulden (1930) believe that "a constant absorption is not practical or desirable in such a series of flours, since the absorption may vary from 57% to 75%." Swanson and Working (1933) state ". . . it is not possible

[11] Part II, paper read by Quick Landis at the meeting of the American Association of Cereal Chemists, Toronto, Canada, June 1934.

[12] It should be pointed out that the fermentation requirement itself is determined by the amount of conditioning necessary to bring the gluten to the ill-defined so-called "ripe" stage. European investigators have long expounded the simple theory, of which Brabender (1934) is the most lucid exponent (*cf.* Molin, 1934), that the "optima" of gas production and gluten condition must coincide for satisfactory baking. But the essential relationship between the two is through the fermentation process. Hence, since this is fixed by the difficultly controllable gluten requirement we must adapt the diastatic activity to it. It is, however, not necessary that the two "optima" coincide, but that the fermentation be maintained beyond the gluten "optimum," as emphasized by Larmour and Brockington (1934).

to get a correct measure of the quality of flour without means of measuring the absorption with some degree of accuracy." Flours may vary from 57% to 75% in absorption, and corresponding variations are made in the formula to suit the flour, *while diastatic activity of the same flours may vary from 80 to over 300* (Rumsey Units) without any compensating changes in the formula being made. The drastic effect of diastatic insufficiency has been often remarked. The gradual change in dough and loaf characteristics accompanying changes in absorption are well recognized. It appears equally advantageous, if not more so, to vary diastatic supplement to suit the flour as it is to vary absorption for the same reason. In view of the several excellent methods (*vide infra*) for determining diastatic activity it is surprising that this has been so rarely considered (Markley and Bailey (1931), Merritt, Blish, and Sandstedt (1932)). Weaver and Fifield (1935) recommend variable mixing times for different classes of wheats. Of 85 laboratories questioned by Aitken in 1934, 84 were using variable absorption, 2 variable mixing, 2 variable sugar, 4 used specifically variable added ingredients. Variable absorption has recently become official in the A. A. C. C. test (see Coleman, 1932, and Geddes, 1934).

It is probable that the doctrine of the fixed type procedure which has been developed during the preceding decade is largely responsible for this condition. After several years of trial, the limitations of the policy of maintaining a fixed formula and procedure for the general testing of a substance with so many variable factors as flour are becoming apparent. Bayfield and Shiple (1933) refer to the "inherent disadvantage of any fixed procedure which necessarily cannot be adapted to meet the individual requirements of each flour." The Canadian chemists, as is well known, early abandoned the fixed type procedure in principle, but instead of varying the formula from flour to flour, baked every flour by a number of fixed formulas (*e.g.*, see Harris (1934), and Aitken and Geddes (1935)); producing some remarkable results and clarifying to a considerable extent certain perplexing problems. Larmour and Sallans (1933) recognize the chaotic direction in which this policy is leading when they state: "Modifications of the baking test have been proposed from time to time by various investigators, but it is extremely difficult to produce evidence that one procedure or formula is better than another." Larmour also said (Proceedings 19th Annual Convention, p. 39, 1932) ". . . we continue to investigate baking formulas in the hope that at some time we would be able to get one or two or three standardized according to procedure, although *not necessarily according to ingredients* . . ." (italics ours). Geddes and Winkler (1930) recognize the formula as a *variable factor* when they state ". . . the data obtained in this study

serve to illustrate the importance of considering the baking formula in dealing with questions of fermentation tolerance." Treloar and Larmour (1931) presenting a statistical analysis of some results of Bailey, Fifield, and Sherwood (1928) conclude that ". . . loaf volumes resulting from a fixed baking technique are largely a reflection of that technique as applied to the flours, and not of the flours themselves." Blish and Hughes (1932) recognize these factors in their reply to Jørgensen (1931) and others (see also Blish's summary of Working's paper in the proceedings of the 20th Annual Meeting of the A. A. C. C., page 18 (1934)). "What Jørgensen and other critics of the basic test fail to appreciate is that the so-called 'Basic procedure method' is merely a *reference* method, and is, as pointed out by Werner (1925), a 'foundation for subsequent tests.'" It is apparent that fixed type procedures for baking tests are inherently inadequate.

Variable Factors *vs.* Fixed Factors

But it is by no means to be concluded from this that the goal of standardized test baking is to become a chimerical will-o-the-wisp impossible of attainment, as certain European writers prophesy.[13] It is believed that the early advocates of the fixed type procedure failed to distinguish between fixed ingredients and fixed factors, in spite of Harrel's (1926) excellent illustrated discussion of "The Variable Factors of Bread Production." They made a great advance in selecting one procedure from the countless number then in existence (Fitz, 1925) and in establishing standard temperature, humidity, oven, and other environmental conditions. Since flour is itself a composite of at least four major variable factors (protein kind,[14] protein amount, diastatic capacity and absorption),[15] it is obvious that to bake a series of flours by a fixed formula or even a series of fixed formulas [16] is to allow these four variables free play, resulting in accurate knowledge of none. The axiom that only one variable at a time must be considered was recognized by the originators of the A. A. C. C. test, but factors were not distinguished from ingredients. *Fixed ingredients* necessitates *variable factors*, flours being what they are; *variable ingredients* only can lead to *fixed factors*. The *fixed type procedure* principle must now be extended to the *fixed factor* concept. The only limitations are concerned with the extent of our knowledge regarding these factors. Three concepts are to be distinguished in this connection:

[13] See Kent-Jones (1934), Geddes, Larmour, and Mangels (1934), and Blish (1934).

[14] Blish (A. A. C. C. convention, 1935) has advanced the hypothesis that protein amount is the important factor, protein kind being of minor if any consideration. Evidence is not yet conclusive on this point.

[15] Platt (1933) summarizes this as follows: ". . . baking quality is really the sum of a number of entirely separate characteristics."

[16] See Geddes, Proceedings 19th Annual Convention A. A. C. C., p. 37, also Aitken and Geddes (1935).

1. Many fixed-type procedures under variable conditions: status of the baking test prior to 1926 (Blish).
2. One fixed type procedure under standardized conditions: *e.g.*, A. A. C. C. test 1926 to date.
3. One variable type procedure under standardized conditions. (This third concept, applied to A. A. C. C. standardized conditions, will be referred to in this paper as the Standard Baking Test, as distinguished from the basic and supplementary procedures (concept 2).)

A test bake formula on this principle would be as follows:

Flour	100%
Water	variable
Yeast	variable
Salt	variable
Diastatic supplements	variable
Other ingredients	variable
Procedure	variable . . .

in order to maintain the following factors constant:

Absorption	Optimum or fixed consistency (*e.g.*, 500° Brabender)
Fermentation rate	*e.g.*, r_m = 2.1 g. sugar/hr. (3%) [17]
Salt effect	Minimum rate of change of osmotic effect (1–1.5%)
Diastatic Supplement	Constant oven point level *e.g.*, of 4.0% sugar
Other ingredients	If influenced by flour variations; sufficient to maintain constant influence, or ***minimum rate of change*** of influence
Mixing	Minimum or at maximum response
Procedure	Depending on the purpose of test

Obviously physical and environmental conditions such as temperature and humidity should be standardized and constant. In the present stage of our technique, when testing a series of flours there will still remain at least two major variable, but related factors; gluten kind and amount, and many minor factors. As our knowledge regarding these grows, they too may be brought under control (*cf.* Geddes, 1933) and relegated to the class of "fixed factors." In fairness to the early advocates of the fixed type procedure it should be noted that the concept of fixed conditions was logically adopted as a philosophical necessity (Werner, 1925), but as previously intimated it was decided to designate the ingredients as among the conditions to be fixed. Baking all flours by these conditions gave loaves of varying types and sizes; a resultant of the free play of all these variable factors. Then came the problem of interpretation. From the loaf so obtained the expert can, by noting crust color, volume, shred, bloom, surface conditions, and internal characteristics, arrive at a fairly good idea of the properties of the flour and the method of treatment for best results. We believe it now possible, however, to extend the accuracy of such obser-

[17] It should be recognized that small variations in rate sometimes occur when various factors such as sugar and nitrogen levels are changed. Eventually these may have to be taken into consideration.

vations, indeed to place numerical figures on many of them, from which bake-shop behavior may be better predetermined. But we also believe that it involves a change in the application of the underlying philosophy of testing to baking. Bohn (1935) describes a method of interpretation which well illustrates the inherent difficulties involved in the problem. It is extremely illuminating to compare Moen's (1935) discussion of grain and texture in this connection (see also Proceedings, 20th Annual Convention, pp. 22–23 (1934)).

Realizing the logic of the principles outlined above, Blish and collaborators (Merritt, Blish, and Sandstedt, 1932) have been led to propose a simplification of the A. A. C. C. basic procedure; the so-called "Short Method":

Flour	100 grams
Absorption	variable
Yeast	3%
Salt	1%
Diastatic supplement	none (variable by inference)

In the present state of our knowledge this represents a satisfactory starting point. Together with the results which have been obtained in standardizing conditions and minimizing errors introduced by handling operations, oven conditions and mixing variations, it allows compensation for most of the major variable factors of a flour. With all major factors but one controlled, the results of a series of bakes may be expected to reflect variations in this factor only.

Diastatic Activity as a Variable Factor in Test Baking

The objection may be offered that situations in which several major factors are uncontrolled seldom arise. It is probable that the reverse is true. Bayfield and Shiple (1933) baked a series of 72 soft wheat flours by the basic procedure. They state ". . . these loaves proved very disappointing . . . gave many indications of lack of sufficient sugar to withstand the long fermentation period." The remark of Treloar and Larmour (1931) quoted above with reference to the influence of the baking procedure on the loaf volumes obtained, certainly indicates that the variable factors have not been limited. Most important, however, are the observations of Mangels (1926), Larmour (1930), and a consideration of the summary of Geddes (1933).

It has become apparent that baking quality is closely related to protein content. Under certain conditions correlation coefficients as high as +.95 have been obtained between loaf volume and protein content; practically a linear relationship (Harris, 1932). Now Mangels (1926), reviewing the relation between protein content and baking quality for a series of years, pointed out that correlations between these two variables were significantly lower in years when diastatic

insufficiency was prevalent. Larmour (1930) confirmed this observation. The response to bromate has also been considered to be highly correlated to the protein content of the wheat of one class. The following values are taken from a summary by Geddes and Larmour (1933):

Crop year	r (Flour protein × bromate response)
1926	.571
1927	.472
1928	.928
1929	.630
1930	.633
1931	.335

Most of these results were obtained by the basic A. A. C. C. procedure on experimentally milled flours. It will be recalled that there were few general complaints regarding diastatic deficiency during 1926 and 1927. The 1928 flours contained a relatively large proportion of immature and frosted kernels—hence the diastatic activity (*cf.* Johnson and Whitcomb, 1927), was adequate even in experimentally milled flours. Again in 1929 and 1930 there was no evidence of a general diastatic shortage in flours, while 1931 was marked in this respect, causing much difficulty in shops and ushering in again the attempts at mill control of this factor. They state "It has been our general experience that baking results by the basic formula are influenced by variations in enzyme activity to a much greater extent than by bromate."

Again any variable factor which is not eliminated or minimized to the best extent of our knowledge will increase the variability between replicates and also the difference which may be taken as significant. This is shown by Treloar and Larmour (1931) who found that the omission of sugar from the basic test approximately doubled the variability. From this and many other examples which could be compiled from the comprehensive work of the Canadian chemists, particularly Geddes and Winkler (1930), Harris (1932a), Larmour and Brockington (1934), Aitken and Geddes (1934) the conclusion is inescapable that diastatic activity has been allowed to confuse the results of a large proportion of baking tests for many years.

Determination of Diastatic Factor before Baking

Again the objection has been offered that preliminary determination of the diastatic capacity involves an undue amount of effort. Any series of flours to be bake-tested are subjected to the analytical determinations for protein, ash, usually moisture and color and, in

addition, absorption. In view of the much greater effect of diastatic activity than these factors on the test results is it not at least equally important also to obtain that value? The question of Hartkopf at the 18th Annual Convention of the A. A. C. C. (Proceedings, p. 27) is pertinent in this connection, *viz.*: "I would like to ask this question; what is the value of being able to run 50 samples a day and not get results" (or accurately interpretable results without additional baking tests) "that are correct results? Better run 10 samples a day and get correct results than run 50 samples that are opposite to the other fellow's results." These remarks were inspired by the conflicting collaborative evidence presented by Swanson and Kroeker (1932a) and based on the premise of determining gassing power *before* baking. Simple and convenient methods for determining diastatic activity and the *practical application* of the results are summarized later in this paper.

The Purpose of Test Baking

This leads directly to that favorite topic of discussion; why bake at all? Aside from the desirability of checking the technique of various laboratories, there are apparently two general reasons for test baking: (1) to evaluate a factor which can be determined in no other way (see the quotation from Mangels and Stoa (1931) above) or for which no more accurate or convenient chemical or physical method has been developed,[18] and (2) as a synthetic test, a check, upon factors which *have* been determined by this or other methods. Hartkopf (*loc. cit.*) replies to this question as follows: "You should run the baking test as a check" (not necessarily as a determination of flour qualities is to be inferred from this statement). "Without first determining the physical properties of the flour and then determining the gassing capacity of flour we are not able to run a baking test intelligently . . . in that baking test, if we do not know those properties, then we do not know what makes up those baking qualities." The baking test, being essentially an integrated and synthetic (as contrasted to an analytic) test, should probably be used primarily as a check, and secondarily for the evaluation of factors capable of determination in no other manner.

Control of Diastatic Factor

Thus with the premise that the diastatic *factor* is to be kept constant, along with consistency and other factors, by the variable *ingredient*, diastatic supplement, in order to check the accuracy of the diastatic determination or to evaluate some *other* factor, the process of

[18] Looking at the proposition conversely: why do we *not* bake to determine absorption or protein content (*cf.* Harris (1932b))? Obviously it is because more accurate and/or convenient methods are available for the determination of these factors.

accurately correcting the diastatic capacity of the flour and correlating it to the fermentation, becomes of importance. Inspection of the sugar level equation reveals that an increase in p, s, or both will lead to an increased concentration of sugar at the end of proof time. Morison (1925) finds that the residual sugar content of a large number of commercial loaves varies from 2.79% to 5.81% (*cf.* Blish, Sandstedt, and Platenius, 1929). Taking for the present 4% sugar as an average adequate value (this is sufficient to maintain fermentation) for the sugar content to be maintained in the test loaf [19] (American flours), and neglecting also for the present the compensating influences operating during oven spring, it is obvious that S_p must exceed S_f at the oven point by 4%. Thus, at the end of total fermentation time:

$$S_F = S_f + 4$$

or

$$\frac{s}{\log 2} \log t + p = r_m(t - l_v) + 4.$$

We are confronted with the problem of so varying s and p in the dough that this equation is satisfied. It has been found that the addition of sugar or non-diastatic malt influences only the value of p, while the use of diastatically active concentrates such as diastatic malt extract raises the value of both p and s. Quantitative investigation of the effect of these latter substances is still under investigation.[20] For the present, then, it will suffice to determine the amounts of the former materials to be added to satisfy the equation.

For 3% standard bakers' yeast r_m and l_v at 30° C. (standard test conditions) are found to be approximately 2.1% sugar per hour and 0.6 hour, respectively. Thus, for example, the amount of sugar fermented at the end of a 3.9 hour (standard test conditions) total fermentation time is 6.9%. To maintain a 4% sugar level in the test loaf, an amount of sugar, as such or in the form of non-diastatic malt, should be added so that with the diastatic activity of the flour the potential sugar level at 3.9 hours will be 10.9%.[21] If the values of s and p are known (see

[19] The idea has frequently been expressed that the amount of residual sugar in the test loaf is of little or no importance provided it is above a certain limiting value. However, variations in this quantity serve to introduce another variable factor which must have some effect. Recently Larmour and Brockington (1934) have presented evidence to show that there is a specific response to sugar independent of its effect on the fermentation. Geddes and McCalla (1934) in comparing results by the bromate and malt-phosphate-bromate formulas on two series of flours of high and low diastatic activity, found that the latter formula largely eliminated the effect of diastatic activity on loaf volume, but noted that the loaf volume of the high diastatic series "is negatively correlated with the diastatic activity of the flour. . . . While neither of the partial correlation coefficients is significant there is indication that the loaf volume tends to be depressed when the diastatic activity is increased beyond a certain point." To increase the accuracy of our results it appears highly advisable to attempt to maintain essentially constant sugar levels, regardless of variations in diastatic activity of flours, just as we do with consistency.

[20] Landis (1935) has investigated the relationship between the amount of diastatic malt added and the sugar levels obtained, and tentatively proposed an equation of the form:

$$S_p = \frac{s}{\log 2} \log t + f \log l \log t + p + Fl,$$

where s, f and F are constants characteristic of the flour and l is the amount of malt extract added.

[21] Landis, Frey, and McHugh (1935), taking into consideration the enzymic action during oven spring, arrive at the figure 11.4% for this value.

succeeding section on methods) this amount can readily be determined from a nomographic chart (see Landis, 1934; *cf.* Table 9). This example will serve to illustrate the method used in calculating the amount of diastatic supplement required for any normal condition. The tables given below may also be found of value.

Methods

Several methods based upon at least three well defined principles have been developed for the determination of diastatic activity.[22] While most of these methods give but a single figure index of the diastatic process, and thus are limited in the accuracy of their application, their use is to be preferred to no compensation at all. They are summarized below, and tables are given by which the results obtained by each method may be applied to the correction of the potential sugar level in the dough. The approximate ranges of probable error may be inferred from the figures. Correlation of enzymic activity to yeast fermentation in the dough by application of the data and tables as indicated in this paper or by other means, should aid in the elimination of diastatic capacity as an uncontrolled factor in test baking.

Reducing Sugar Methods

Rumsey Method:—The principle of the Rumsey Method is illustrated in Figure 2. It consists essentially in determining the slope of the secant drawn as shown. As originally devised by Rumsey, it involved two determinations, the original *reducing* sugars in the flour and the reducing sugar level after one hour, at the normal pH of the flour. Mangels (1926a), Malloch (1929), and finally Blish and collaborators (1933) have provided pH control and developed it to a high degree of accuracy (see also the recent work of Geddes and Eva, 1935). Blish and Sandstedt (1933) finding that the amount of reducing sugars initially present was small and relatively constant, recommended dispensing with the blank determination except in the case of unsound flours.

[22] It has been proposed to use the baking test as a measure of diastatic activity. In view of the discussion above regarding the purpose of test baking, the inadequacy of such a proposal is evident. Moreover, Method 3, described below, indicates that it is unnecessary to light the oven in order to determine diastatic activity. In addition, the accuracy of such a determination is anything but great. All the artistry of the expert baker is hardly requisite to translate the diagnostic symptoms of the test loaf into a concrete recommendation for the correct amount of diastatic supplement required to maintain a predetermined sugar concentration in the test loaf. Heald (1932) states ". . . the use of the baking test as a measure of diastatic value with its many uncontrolled factors is often misleading." In addition, such a policy entails a needless amount of work. Bayfield and Shiple (1933) correctly re-baked their series of 72 flours with the addition of diastatic supplement before drawing conclusions (Bayfield (1935) now uses 5% sugar in his tests, probably following the suggestion of Blish). Blish and Hughes (1932) maintain that ". . . it is possible even with the A. A. C. C. *basic method alone* to go a long way in interpreting the test loaf both from the standpoint of gluten properties and 'gassing power.' A small, very pale loaf indicates exhaustion of the gas production factor, *i.e.*, fermentable sugar, and *necessitates rebaking* (our italics) by one of the supplementary procedures previously mentioned in order to permit gluten properties to register." It is obvious that this involves at least two bakes; in addition, but an approximate idea as to the amount of supplement required can be obtained. It is possible to obtain a rough idea of the diastatic factor by test baking, but *quantitative conclusions regarding other factors* are not then valid (*cf.* Bayfield and Shiple, 1933). Let us eliminate all the known variable factors that we can; there will still be enough unknown and uncontrollable factors to make interpretation of the resulting test loaf difficult for the average technician.

They give directions for the determination according to the latest and most accurate procedure. Modifications of this method have been proposed in which polariscopic or refractometric measurements are used. Practical application awaits only correlation of these values to actual sugar levels.

It is obvious, however, that the results of this method, neglecting as it does both initial non-reducing sugar content and the rate of diastasis

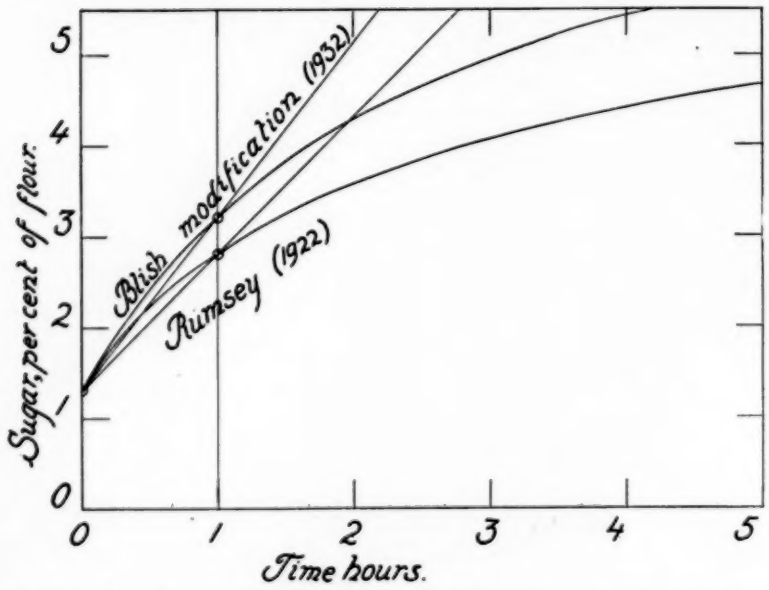

Fig. 2. Reducing sugar methods (*cf.* Malloch, 1929). The curved lines show the diastatic, and in this case, the actual sugar level as a function of time. No yeast is present in the mixture.

subsequent to the first hour,[23] offer at best but an approximation to the amount of diastatic supplement required in a given test. Approxima-

TABLE II

PROBABLE SUGAR LEVELS AS ESTIMATED FROM VARIOUS RUMSEY VALUES

Rumsey value pH 4.7 30° C.	Probable		Probable sugar level at				
	1° value %	2° value %	1 hr.	2 hr.	3 hr.	4 hr.	5 hr.
Below 100	1.5–2.7	.1–.5	1.5–2.7	1.6–3.2	1.6–3.4	1.7–3.6	1.7–3.8
100–200	2.0–3.0	.1–.7	2.0–3.0	2.1–3.7	2.1–4.1	2.2–4.3	2.2–4.5
200–300	2.5–4.0	.3–1.2	2.5–4.0	2.8–5.2	3.0–5.8	3.2–6.3	3.3–6.7
Over 300	over 3.5	over .7	over 3.5	over 4.2	over 4.5	over 4.8	over 5.0

[23] Compare, however, Sandstedt's (1934) 4-hour total sugar levels in suitably buffered suspensions, which coincide well with those in 3% yeast doughs.

tions to the probable sugar level for various Rumsey values, based upon a limited number of actual analyses of different types of flours are given in Table II. From them the range of supplement required for the standard baking test conditions may be deduced.

TABLE III

PROBABLE DIASTATIC SUPPLEMENT REQUIRED FOR STANDARD BAKING TEST AS ESTIMATED FROM THE RUMSEY VALUE OF THE FLOUR

Rumsey value	Probable diastatic supplement	
	Sugar	Non-diastatic malt equivalent
Below 100	6%–4%	8%–5%
100–200	5%–3.5%	6.5%–4.5%
200–300	4%–2%	5%–2.5%
Over 300	3%–1.5%	4%–2%

FERMENTABLE SUGAR METHODS [24]

Blish Precision Method (Blish, Sandstedt and Astelford, 1932):— This is a fermentation method, the principle being indicated in Figure 3, and thus includes the sugars initially present in the flour. In

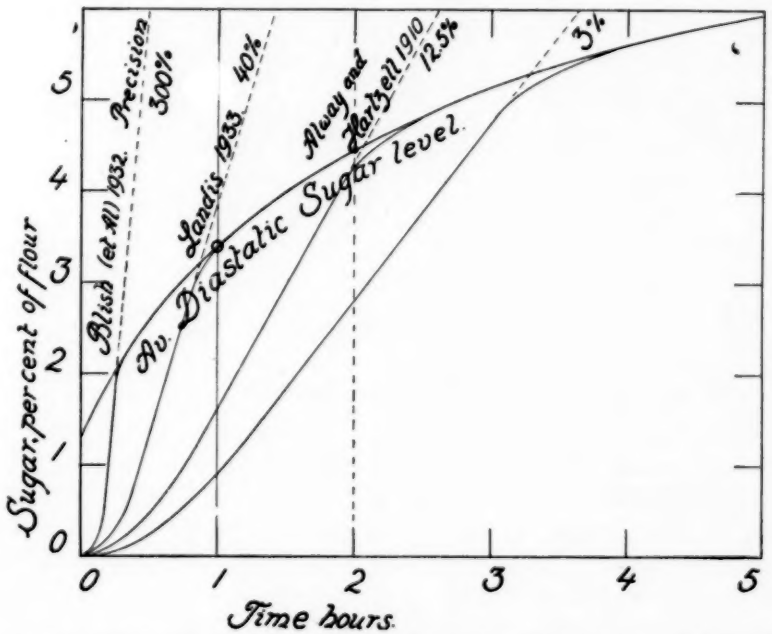

Fig. 3. Fermentable sugar methods. The fermentation (lower) curves show the different conditions under which the diastatic level has been determined.

[24] Davis and Worley (1934) have shown the high degree of correlation between Rumsey diastatic activity and gassing power.

addition, the end product concentration is at a low and relatively constant value—thus approaching conditions in the dough more closely than the Rumsey Method. The results are expressed in millimeters of mercury pressure, but as the originator intimated, the apparatus may be easily calibrated to read in percent sugar. This value, taken at one hour, is substantially the same as the primary saccharogenic value as previously defined. It offers a more convenient and accurate method of estimating the amount of diastatic supplement required than the Rumsey Method. It possesses the further advantage of the ability to indicate the secondary value by prolonging the test to the second hour. For details of the procedure refer to Blish, Sandstedt, and Astelford (1932), and Blish and Sandstedt (1933).

TABLE IV

PROBABLE SUGAR LEVEL AS ESTIMATED FROM THE BLISH PRECISION TEST

Pressure mm. Hg.	Probable		Probable sugar level at				
	Primary value	Second value	1 hr.	2 hr.	3 hr.	4 hr.	5 hr.
50	1.2	.1–.3	1.2	1.3–1.5	1.3–1.7	1.4–1.8	1.4–1.9
100	2.4	.3–.5	2.4	2.7–2.9	2.8–3.2	3.0–3.4	3.1–3.6
150	3.6	.4–1.0	3.6	4.0–4.6	4.2–5.2	4.4–5.6	4.5–5.8
200	4.8	.7–1.3	4.8	5.5–6.1	5.9–6.8	6.2–7.2	6.4–7.6

TABLE V

PROBABLE DIASTATIC SUPPLEMENT REQUIRED FOR THE STANDARD BAKING TEST AS DEDUCED FROM THE BLISH PRECISION METHOD

Pressure mm. Hg.	Probable supplement required	
	Sugar %	Non-distataic malt equivalent %
Below 50	7.0–5.5	9.0–7.5
50–100	5.5–4.5	7.5–6.0
100–150	4.5–3.5	6.0–4.5
150–200	3.5–1	4.5–1.5

There are two factors in this method which make it subject to criticism because of serious errors and variability introduced. They are probably due to the excessive amount of yeast (300%) and water (1600%) used; conditions quite dissimilar to those in the dough. In the improved method (Sandstedt and Blish, 1934) these objections have been overcome and reliability greatly improved, although the 1-hour sugar level is not indicated. The principle of the improved method is illustrated in Figure 2 by the 3% yeast curve.

Along with the development of this method a modification based upon the same principle was developed at these laboratories (Landis,

1934). The essential difference lies in the use of 50 g. flour, 125 cc. water (250% absorption), 20 g. yeast (40%), 1% salt, and 1% peptone. (If the peptone is omitted the yeast should be increased to 50%.) The gas produced is measured either at constant volume or at constant pressure, converted to percent sugar and sufficient readings are taken to determine both the primary and secondary saccharogenic values. This defines the course of the diastasis throughout reasonable fermentation times within the limits indicated in the discussion above and, by the use of the nomographic chart, enables adequate compensation for diastatic activity to be made.

Determination of the Critical Point

It is also obvious that a determination of the sugar level at the critical point in an actual dough containing an amount of yeast not far

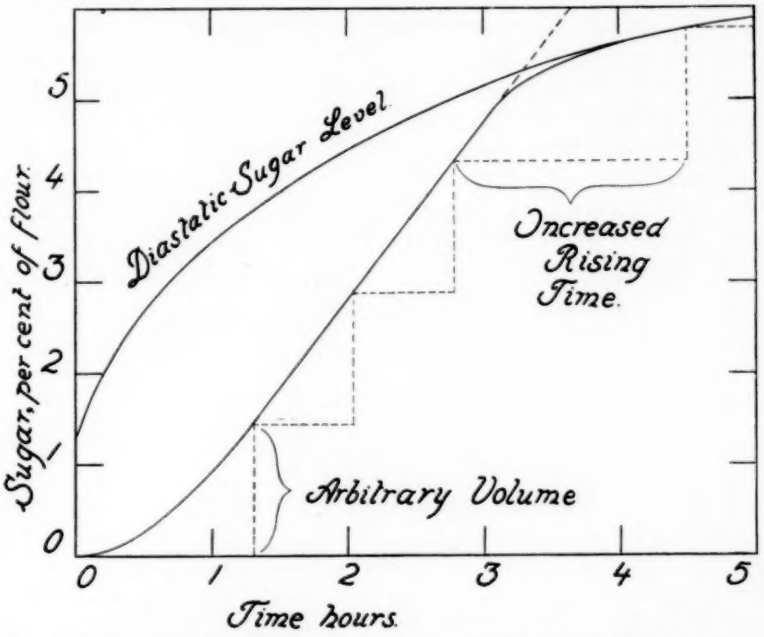

Fig. 4. Critical point methods. The vicinity of the critical point is identified by the sudden decrease in rate of rise of the dough, or is located in that time interval during which the first large increase in rising time occurs.

different from that used in actual practice would furnish data from which an estimation of the amount of diastatic supplement could be made. This point can be determined in any bake-shop with almost any required degree of accuracy by using the dough itself as the gas container (Frey, 1933). A fermentation jar of suitable proportions serves admirably. The principle is illustrated in Figure 4. A dough

containing, say in this case, 3% yeast is prepared without sugar. The addition of shortening makes the dough handle more easily and does not decrease the accuracy of the determination. The dough is allowed to rise to any arbitrary pre-determined volume as identified by a mark on the jar, which must be less than that at which the rate of loss of gas from the dough becomes appreciable. The time at which the dough reaches this volume is recorded, the dough removed from the jar and thoroughly punched, taking pains to expel as much of the gas as is possible. It is then replaced in the jar and the process repeated until a marked increase in the time of rising is produced. The approximate total time at which this occurs is noted and the amount of sugar fermented corresponding to this time is calculated from the equation $S_f = r_m(t - l_v)$, where r_m and l_v have the approximate values 2.1% sugar per hour and 0.6 hour respectively for 3% yeast, or is estimated from Table VI. The actual sugar level at any time is estimated from Table VII, or it may be taken from the nomograph, by assuming an appropriate secondary value. In general, the ranges of secondary values which have been obtained from a limited survey of various flours are given in Table VIII.

TABLE VI

RELATION BETWEEN TIME OF OCCURRENCE OF CRITICAL POINT AND SUGAR CONCENTRATION AT THE CRITICAL POINT—STANDARD BAKING TEST CONDITIONS

Critical point	3% yeast, 30° C. S_f % (approx. value)
Hrs.	
1	1
2	3
3	5
4	7
5	9

TABLE VII

PROBABLE SUGAR LEVELS AS ESTIMATED FROM A DETERMINATION OF THE CRITICAL POINT—STANDARD BAKING TEST CONDITIONS

Probable secondary value	3% yeast, 30° C. Probable sugar level in % at				
	1 hr.	2 hr.	3 hr.	4 hr.	5 hr.
.1–.5	1	1.1–1.5	1.1–1.7	1.2–2.0	1.2–2.2
.3–.8	2.2–2.7	3	3.2–3.5	3.4–3.8	3.5–4.1
.5–1.0	3.4–4.2	4.4–4.7	5	5.2–5.4	5.4–5.7
.7–1.5	4.2–5.6	5.7–6.3	6.4–6.7	7	7.3–7.5
1.0–1.7	5.0–6.8	6.8–7.8	7.8–8.3	8.4–8.7	9

TABLE VIII

SECONDARY VALUES OF VARIOUS TYPES OF HARD WHEAT FLOURS

Flour type	Range of 2° values, %
Southwestern experimentally milled	.1–.3
Southwestern commercially milled	.3–.8
Northwestern experimentally milled	.3–.8
Northwestern commercially milled	.5–1.3
Treated flours	.5–1.8 or more

It is apparent from an inspection of Figure 4 that the smaller the arbitrary volume selected for the punch the greater the accuracy of the determination of the critical point will be, but more attention will be required of the operator. The Brabender Fermentograph is an instrument which automatically records the course of the fermentation and determines this point with great accuracy. An arbitrary volume of 1180 cc. to the bottom of the meniscus has been used (Frey, 1933) with a 300 g. dough and 2% yeast. A pint mason jar serves admirably for the Standard A. A. C. C. baking test conditions. Using the official fermentation bowl it is difficult to determine exactly when the bottom of the meniscus reaches the rim of the bowl, but the time when the top of the meniscus reaches the top of the bowl can be easily determined. Although this latter method allows the accurate determination of the critical point, it involves punches at about 22-minute intervals, which is usually too short for conditions in the average control laboratory. The mason jar is to be recommended.[25] As an example, the results obtained on a flour by running these modifications simultaneously are given in Table IX.

TABLE IX

PUNCH TESTS FOR THE CRITICAL POINT

Flour, grams	Jar used	Successive punches, minutes	Critical point, hours
300	1180 cc. Battery	95, 60, 55, 70, 130	4.2
100	Pint mason	82, 53, 47, 51, 52, 98	4.7
100	Official bowl, full rise	108, 72, 66, 85, 160	less than 5.5
100	Official bowl, restricted rise	45, 30, 22, 21, 21, 20, 22, 21, 20, 21, 22, 53	4.4
Fermentograph			4.4

SUMMARY

Application of the conclusion reached in the first part of this paper seems to involve a fundamental change in the application of the philosophy of testing to the baking process.

[25] A quart jar, cut off just below the narrow portion also serves admirably, and the dough is extracted with facility.

The following axioms are reiterated:

a. Flour, a single ingredient, is a complex of at least four major variable factors: protein kind, protein amount, diastatic activity, and absorption.

b. In an analytical test it is ordinarily impossible to determine accurately more than one factor or variable at a time.

c. In a series of baking tests the fixed type procedure, *i.e., fixed formula,* leads to *variable factors,* flours being as complex as they are; conversely, to maintain *fixed factors* necessitates a *variable formula.*

Aside from checking apparatus and technique there are only two major reasons for test baking:

1. As an analytical test to evaluate a factor which can be determined more accurately and/or easily in no other way.
2. As a synthetical or integrated test; to serve as a check upon factors determined by this or other methods.

Diastatic (saccharogenic) activity, primarily an environmental factor capable of ready quantitative determination, should be removed from the class of variable factors and relegated to the class for which adequate compensation is made by formula variation, along with absorption.

A summary of methods for practically achieving this result is given.

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THE ROLE OF THE LIPIDS IN RELATION TO FLOUR QUALITY

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There exists in the literature of cereal chemistry much fragmentary and conflicting evidence regarding the role of the lipid constituents of wheat in relation to flour quality. Even such a seemingly simple problem as the effect of ether extraction on flour quality is a subject of disagreement. Most investigators believe that flour which has been extracted with ether is improved in baking quality, particularly in volume and texture. Salomon (1908), Winton (1911), Mohs (1924), Johnson (1928), Geddes (1930), and Johnson and Whitcomb (1931) have all presented data of this nature. On the other hand Martin and Whitcomb (1932) found that while some flours (Marquis) were improved in baking quality by ether extraction others (milled from Kubanka and Federation wheat) were harmed, especially in volume. These authors state that gluten quality is probably determined more by differences in the chemical constitution of the gluten proteins and their physical-chemical environment than by the presence or absence of fat-like substances. A few workers (Stockham (1920), Research Association of British Flour Millers (1932)) have found impaired baking quality with ether-extracted flour when compared with the original flour. Johnson (1928) states that reducing sugars and diastatic activity are higher in an ether-extracted flour than in the unextracted flours. Johnson and Whitcomb (1931) found that doughs prepared from ether-extracted flours were markedly superior to natural flour doughs in their ability to retain the carbon dioxide produced during fermentation. The addition of fat to doughs prepared from ether-extracted flours reduced their gas-retaining properties. Needless to say, all investigators have found an improvement in crumb color on ether extraction.

Working (1924) found that prolonged washing of the soft gluten from low grade flour removed phosphatide and gradually increased the tenacity until the gluten was practically equal to that from patent flour. Working (1924) states also that the addition of phosphatides to flour (0.5–1%) injured gluten quality as measured by the feel of the gluten, viscosity determinations and baking tests. In a later

paper Working (1928) says that a small amount of phosphatide, such as is normally present in a good patent flour, might possibly have a beneficial effect. Walde and Mangels (1930) have suggested that improvement in the baking quality of flour by natural aging, certain bleaching agents, and potassium bromate, might be due to oxidation of unsaturated fatty materials associated with the gluten. Geddes (1930) in a very interesting research found that the addition of wheat germ (5%) had a deleterious effect on the baking quality of flour (fifth middlings). Increased fermentation time, additions of potassium bromate, and heat treatment of the germ, all reduced its deleterious effect. Oxidation of certain germ constituents, presumably the phosphatides, is suggested by Geddes as the primary change involved in such improvement. Rich (1934), in his study of the Agene treatment of flours and of wheat germ, suggests that improvement due to artificial maturation is caused by some reaction which apparently involves the oxidation of some constituent of the germ content of flour. He does not agree with the hypothesis that the phosphatides are the constituents responsible for this reaction. Kosmin (1934, 1934a, and 1935) has observed that free unsaturated acids produce the same effect as natural aging in strengthening the gluten. According to Kosmin, the free unsaturated fatty acids influence the colloidal behavior of the gluten, thickening the gel. Saturated fatty acids show no such effect. Kosmin believes that temperature is the most important factor influencing the aging of flour and that this process proceeds without participation of oxygen since fat hydrolysis does not require the presence of oxygen. The chemical effect of artificial aging by means of bleaches was found to be different from natural aging and was thought to be connected in some way with the action of oxidizing agents on the proteins of flour. Resnitschenko and Popzowa (1934), in an extension of Kosmin's work, found that the effect on gluten of unsaturated acids was not due to their acidity as such but to the presence of the group R−CH : CH COO M where R = radical and M = a metal or hydrogen. Salts of the unsaturated fatty acids caused the same action as the acids themselves. Oxalic acid, formaldehyde, silver nitrate, and sulfuric acid also had a similar effect. Both Kosmin and Resnitschenko and Popzowa judged the action of these compounds only by the feel of a hand-washed gluten.

Work on the lipid constituents of wheat has been conducted in this laboratory for about ten years. Although many phases of this research are still incomplete from both the theoretical and practical standpoints, we believe that some of the facts already found will clarify the conflicting ideas on this subject sufficiently to justify their publication at this time. A study of the lipids of the wheat embryo

was made by one of the authors (Sullivan, 1935) and, in connection with this work, several fractions and individual acids obtained directly from the wheat germ were available for use in determining their influence on flour quality.

It is well known that the presence of increasing percentages of wheat germ in flour harms the baking quality in proportion to the amount of germ present. Most chemists have assumed that the bad effect of wheat germ (whether present accidently during the milling procedure or added deliberately) was due to some fat-like constituent. Only a few dissenters have suggested that some constituent other than the ether or alcohol-ether soluble fraction of germ was responsible for its harmful effect on baking quality. Our first problem resolved itself into the determination of the effect of fat from wheat germ and of each fat fraction and its hydrolytic products on normal sound patent flour as judged by gluten washing and baking tests as well as by the Farinograph and Fermentograph. Fat from fresh germ was not found to be deleterious to the baking quality of a flour and the only germ-fat constituents which were found to be injurious were the unsaturated fatty acids which develop upon aging due to hydrolysis of the triglycerides and, what is much more important, the subsequent oxidation products of these unsaturated acids.

Inasmuch as none of the fractions of fresh germ fat was found to be harmful to the baking quality of flour, it was decided to investigate the baking quality of ether-extracted flour.

Experimental

The lipids from an alcohol-ether extraction of fresh wheat germ have been found to be composed of about 4% of unsaponifiable material (of which about 70% is a mixture of sterols) and mixed triglycerides which on hydrolysis gave the following amounts of fatty acids: palmitic, 11.76%; stearic, 3.05%; lignoceric, 1.19%; oleic, 28.14%; α linolic, 22.32%; β linolic, 29.99%; α linolenic, 1.83%; and β linolenic, 1.72%. Approximately 16% of saturated fatty acids were found. As might be expected, no fully saturated glycerides were present—the fat being composed largely of mixed mono-saturated-di-unsaturated and tri-unsaturated glycerides (Sullivan, 1935). Full details concerning the separation of the saturated acids of the unsaponifiable material and the isolation and purification of many of the compounds used in this investigation as well as their melting points and ultimate analyses may be found in the above quoted reference.

The iodine numbers given in this paper were all conducted by the Rosenmund-Kuhnhenn method (1923).

A short patent flour milled from hard spring Marquis wheat was employed in these experiments and the action of fresh germ, total germ fat, germ fat fractions, pure triglycerides, and pure fatty acids was determined by means of the Farinograph, Fermentograph, hand washed glutens, and, finally, by the baking test. Baking results are given in Table I, and gas-production data in Table II. The most representative farinograph curves are reproduced and shown as Figure 1.

The weight of flour used for the baking test was equivalent to 300 g. at 13.5% moisture. Expansion loaves were made with the

TABLE I

EFFECT OF DIFFERENT GERM FAT CONSTITUENTS ON BAKING QUALITY

Sample	Dough quality	Loaf volume 100% basis
Standard patent flour	Strong, elastic	100
Standard patent flour, 10% of flour replaced by 10% fresh germ	Poor, soft, sticky, short	61
Standard patent flour, 10% of flour replaced by 10% ether extracted fresh germ	Poor, soft, sticky, short	62
Standard patent flour, plus 1% germ fat	Strong, elastic	102
Standard patent flour, plus 1% triolein	Strong, elastic	100
Standard patent flour, plus 1% tripalmitin	Strong, elastic	100
Standard patent flour, plus 0.07% mixed sterols from germ fat	Strong, elastic	100
Standard patent flour, plus 0.03% non sterol fraction of unsaponifiable material from germ fat	Strong, elastic	101
Standard patent flour, plus 1% total fatty acids from germ fat	Strong, elastic	98
Standard patent flour, plus 1% total saturated fatty acids from germ fat	Strong, elastic	100
Standard patent flour, plus 1% palmitic acid	Strong, elastic	99
Standard patent flour, plus 1% stearic acid	Strong, elastic	98
Standard patent flour, plus 1% oleic acid	Fairly strong, elastic	98
Standard patent flour, plus 1% linolic acid (technical)	Strong, slightly short	93
Standard patent flour, plus 1% total unsaturated fatty acids from germ fat	Fairly strong, elastic	96
Standard patent flour, plus 1% total unsaturated fatty acids mixed with flour 7 days before baking	Fair, short	88
Standard patent flour, plus 1% total unsaturated fatty acids exposed to oxygen for 7 days	Poor, short	86
Standard patent flour, plus 0.18% linolic tetrabromide (m.p. 113.5°)	Strong, elastic	101
Standard patent flour, plus 0.5% sativic acid (mixed α and β)	Strong, elastic	100
Standard freshly milled straight (14.00% protein)	Strong, elastic	100
Aged straight (9 months old)	Good, short	93
Ether extracted aged straight	Strong, little tough	76
Ether extracted aged straight, plus 1% fat from freshly milled flour	Strong, elastic	98

TABLE II

GAS PRODUCTION IN DOUGHS IN FERMENTOGRAPH UNITS

Sample	Gas production		
	3rd hour	4th hour	Total gas 6 hours
Standard patent flour, 13% protein	680	180	2495
plus 1% germ fat	580	155	2245
plus 1% triolein	615	150	2290
plus 1% tripalmitin	670	170	2460
plus 1% total fatty acids from germ fat	285	100	2005
plus 1% stearic acid	450	110	2130
plus 1% palmitic acid	580	140	2250
plus 1% oleic acid	310	100	2025
plus 1% technical linolic acid	420	120	2105
Ether extracted patent flour	730	175	2480
plus 1% germ fat	890	200	2680
plus 1% flour fat	770	170	2420

following formula: 3½% yeast, 1½% salt, 4% sugar, 2¾% lard, and 0.25% yeast food (Red Star). The absorption was determined on the Farinograph by the method described by the authors in an earlier paper (Near and Sullivan, 1935). The loaves were proofed to a definite height (unless the loaf failed to come up in proof) in a Bailey-Walker cabinet and the bread volume measured by seed displacement 20 to 25 minutes after removal from the oven.

Farinograph curves were made by adding sufficient water to produce a maximum consistency of 580 units with a total dough weight of 480 g.

Doughs were prepared for the gas-production tests in the Fermentograph with a formula of 3% yeast, 1% salt, and without sugar. They were mixed to optimum development at 500 units in the farinograph mixer. The doughs were punched down and the recording device set back to zero at the end of each hour over a six-hour period.

Where germ was used in these experiments, 10% of the flour weight was replaced by the germ. Since the ether extract of wheat germ amounts to at least 10% and the amount of germ used was 10% of the total combined flour and germ weight, 3 cc. or approximately 1% of germ fat was employed. Most of the other compounds were used in this same amount (about 1%) for purposes of comparison and maximum effect, no attempt being made to employ each fraction in exactly the amount in which it occurs in germ fat. In addition to the fat constituents given in Tables I and II, the following materials were tried and found to have no appreciable effect on the farinograph curves: 0.05% unsaponifiable matter from wheat germ, 0.05% dihydroxystearic acid (prepared by oxidation of the oleic acid from the unsaturated fatty acid fraction obtained from wheat germ), 1% egg lecithin, and 1% glycerine.

Fresh germ added to the flour caused a pronounced decrease in loaf volume and curve 2 indicates how badly it damaged the gluten as shown by the Farinograph. Ether-extracted germ showed no improvement whatever over the original unextracted sample. As

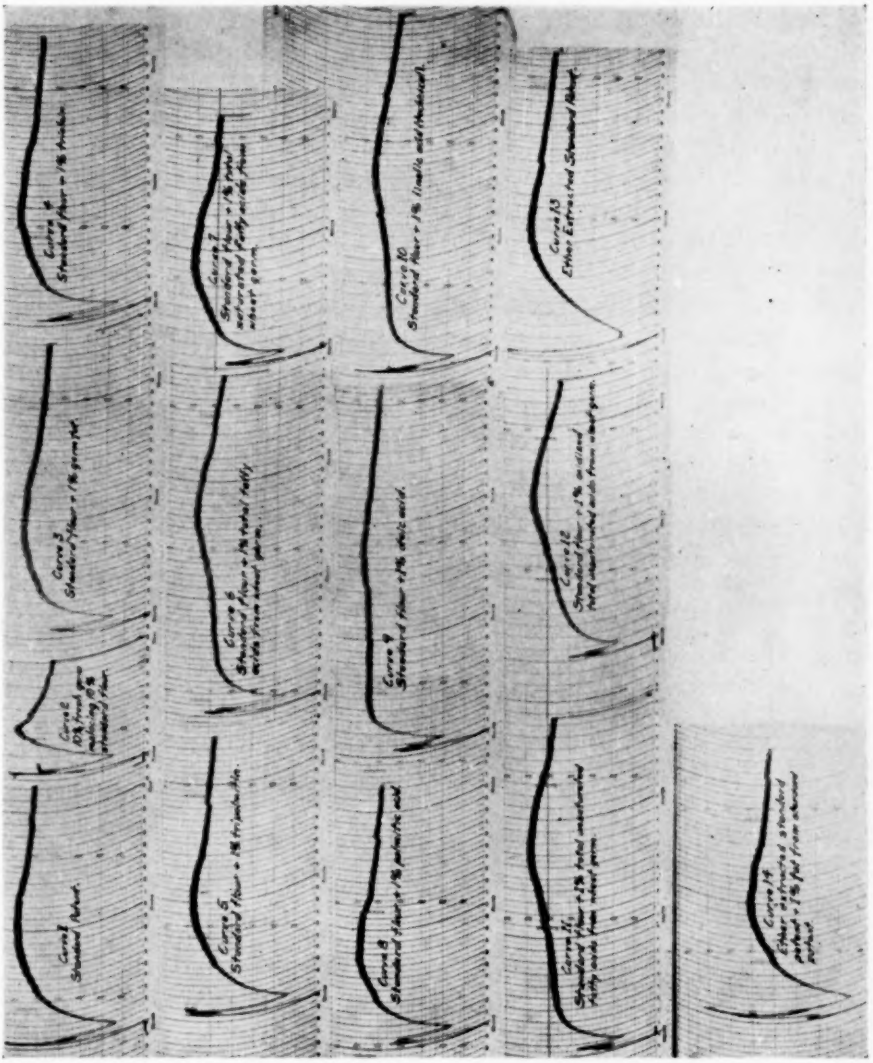

Fig. 1. The effect of different germ-fat constituents on flour quality as measured by the Farinograph.

would be expected from the foregoing results, germ fat itself had no harmful effect on loaf volume—showing quite conclusively that the injurious character of germ is not in the fat fraction. When lard was omitted from the formula, the loaf volume was decreased to 86%

of the standard. The absence of lard lowers the volume of an expansion loaf more than it would a commercial loaf. Using germ fat (ether extracted) in place of lard as the shortening, gave a loaf volume of 96%, not quite up to the volume when lard was employed. This experiment again shows that fresh germ fat is not harmful to the baking quality of a flour, although it does not have quite as good shortening properties as lard. The marked detrimental action of germ itself on the baking quality of flour and the identification of the compounds causing this effect will be discussed in another paper.

Four pure triglycerides—trimyristin, tripalmitin, tristearin, and triolein—were tried for their effect on the farinograph curve of the patent flour. The trimyristin was prepared from nutmeg and recrystallized three times from ethanol. The tripalmitin and tristearin were Eastman products and the triolein made by Kahlbaum. The saturated glycerides showed no effect (an example is given in curve 5). Triolein (curve 4) made a curve very similar to that produced by the addition of germ fat (curve 3) which exhibited a very slight "shortening" effect on the gluten. The similarity between triolein and germ fat was to be expected since germ fat is composed of about 95% triglycerides, most of which are mixed glycerides containing at least two unsaturated acids. The best triglycerides to have used for these experiments would have been mixed triglycerides containing a rather large proportion of linolic acid as well as oleic, palmitic, and linolenic acids. The synthesis of such compounds is quite difficult owing to isomerization and wandering of the acyl group. Only the simple glycerides, therefore, were employed.

The mixed sterols and the non-sterol fraction from the unsaponifiable material of wheat germ were used in small amounts because of their existence in such small quantities in wheat germ fat. Their effect on the farinograph curve and in the baking test was not detectable.

The total saturated fatty acids (obtained by the Twitchell procedure), curve 7, as well as stearic and palmitic acids, had a very slight "shortening" action on the flour-water curves. The only marked change on the farinograph curves is displayed upon the addition of any of the unsaturated fatty acids, either the total unsaturated fatty acids from the wheat embryo (curve 11) or the individual fatty acids, oleic (curve 9), and linolic (curve 10). The linolic acid first used was a technical grade so, for comparison, the acid was prepared in a pure state from linolic tetrabromide (m.p. 113.5) from wheat germ fat by the debromination method of Rollet (1909). A series of curves was made with this pure linolic acid compared with corresponding amounts of oleic acid, technical linolic, and the mixed

unsaturated acids from germ fat. The effect on the curves in this series was least with oleic and technical linolic acids, then pure linolic acid and finally greatest with the unsaturated fatty acids recovered from germ fat. This progression, therefore, is correlated with the degree of unsaturation since the unsaturated acids from germ contain some linolenic acid in addition to oleic and linolic acids. When any of these unsaturated fatty acids were added to flour and glutens were washed from the mixture, brittle, crumbly glutens were recovered as Kosmin indicated. When baked, however, the resulting dough quality was not short and was only slightly impaired. The loaf volume decreased only a little, except in the case of the technical linolic acid which had an iodine value of 80. This low iodine value indicates considerable saturation of the double bonds, no doubt caused by oxidation during aging.

In order to investigate further this discrepancy between the pronounced effect of the unsaturated fatty acids on the farinograph curves, the similar marked action on the hand-washed gluten and the unexpected comparatively good baking results, another series of experiments was conducted on the unsaturated fatty acids from wheat germ. Using amounts ranging from 0.2% to 1% in the baking test, it was found that the decrease in loaf volume was directly proportional to the amount of unsaturated acid used. However, even with 1%, the loaf volume decrease was only 4% of the standard. Flour contains slightly more than 1% lipids, and 1% of fatty acids would be approximately the same amount as if all the fat were hydrolyzed.

However, after the mixed unsaturated fatty acids were thoroughly mixed with the flour and the flour stored for one week before baking, the dough quality was only fair and was short (contrasted with the strong, elastic dough from the original flour), and the loaf volume was lowered 12%. A sample of the unsaturated fatty acids (iodine number 154) was poured in a thin layer in a Petri dish and placed in a desiccator which was filled with fresh oxygen each day for seven days. After this exposure, the iodine value had been lowered to 108. The unoxidized fatty acids gave a brittle gluten which still had strength and was tough, but the oxidized unsaturated acids produced a shorter, weaker, and more crumbly gluten. The unoxidized sample had a sweet, oily odor, but after oxidation, the odor was tallowy and rancid. These odors carried through the baking and were very noticeable in the aroma and flavor of the bread. Farinograph curves and baking results are given for the unsaturated fatty acids before and after exposure to oxygen. The oxidized, unsaturated fatty acids produced extremely harmful results on the dough quality, which was made poor, short, and dead. The dough had very poor gas retention.

Loaf volume was lowered 14%. This proves that although the fresh, unsaturated fatty acids produce the effect of age as indicated by the washed gluten (as Kosmin found), the oxidation of these fatty acids is necessary for much influence on the baking value of a flour. As the unsaturated acids are oxidized, the resulting farinograph curve (12) becomes more like the standard flour curve. This makes "shortness" due to age very difficult to interpret from the farinograph curve.

Kosmin (1934, 1934a, and 1935) classified flour samples in several groups ranging from very weak to very strong and claimed that natural aging or addition of free, unsaturated fatty acids moved a flour up the list toward strength and, therefore, believed that aging increased the strength of the gluten of flours. Kosmin also states that the process of flour aging proceeds without participation of oxygen. In our experience with strong hard spring wheat flours during the past few crop years (1934 and 1935) even moderate aging, as for example two to three months, does not improve their gluten quality. It may be, however, that European flours because of their weaker gluten characteristics would show strengthening on aging.

Almost every milling laboratory is familiar with examples of old, broken down, or so-called "shot" flours. These flours generally exhibit a short gluten and their baking quality is impaired to a large degree. A practical example of such a flour was found in the case of a straight grade, freshly milled flour, which was shipped to New Orleans by barge in October and held in storage until July. A portion of this flour was sent to the laboratory for testing and it was found that the gluten and dough quality as well as the loaf volume were harmed considerably by this nine months' aging in a rather warm climate. Some of this aged straight was ether extracted and the fat recovered had an iodine value of 107 and an acid number of 49. Four samples were baked—a freshly milled standard straight flour, the aged straight, the ether-extracted aged straight and the ether-extracted aged straight flour to which had been added 1% of fresh flour fat. The addition of fresh flour fat to the ether-extracted flour brought the dough quality back to standard and the loaf volume up to 98%. The gluten and protein in this aged flour must not have been harmed, for the removal of the fatty acids and their oxidized products and the subsequent replacement by fat from a fresh, sound flour brought the aged flour back to normal. The removal of the fatty acids by ether extraction in no way rejuvenated the flour. The ether-extracted flour gave a lower loaf volume than the aged sample before ether extraction. It is necessary to add fresh fat to the ether-extracted sample before flour can be rejuvenated. In these observations we differ from the results of previous workers on this subject.

Linolic tetrabromide (m.p. 113.5°, Br. 53.17%) was prepared from the unsaturated acids of wheat germ. It was of interest to experiment with this compound since oxygen added to the double bonds caused such a pronounced over-aged effect. Nitrogen trichloride, although generally referred to as an oxidizing agent, could function as a chlorinating agent as well and one of its reactions might conceivably be the halogenation of the double bonds of the glycerides or fatty acids with the formation of a compound similar to linolic tetrabromide. The latter compound (0.18%) was tried in the Farinograph and in the baking test, the data for which is given in Table I. No effect was noticed (with the amount used) either in the curve, the dough quality, or the finished loaf.

The mechanism of the aging of flour as seen by the authors may be outlined as follows: the lipids of freshly milled flour on storage (particularly at a relatively high temperature and moisture content) are hydrolyzed by lipases to free fatty acids. Of these acids, only the unsaturated ones have any appreciable effect. The result is a "shortening" of the gluten. Sometimes this is an advantageous change; more often, it is not, everything depending on the original gluten quality.

So far, our results agree well with the excellent research of Kosmin, with the exception that our American flours do not apparently show the improvement which European flours do by the presence of free, unsaturated fatty acids. However, it has been found that after these unsaturated acids are liberated, oxidation by the oxidases present in flour, by the oxygen of the air, or both, takes place with the result that not only is the gluten made decidedly "shorter" and more crumbly than with the unoxidized fatty acids but the baking quality is seriously damaged. The baking quality of a flour is only very slightly impaired by the presence of even rather large amounts (1%) of unsaturated fatty acids. It is thought that the oxidized fatty acids are peroxides rather than hydroxy acids. The pure tetrahydroxy stearic acids of both isomeric forms (α sativic acid, m.p. 155°, and β sativic acid, m.p. 172.5°) were obtained from the permanganate oxidation of the unsaturated acids of wheat germ. The α and β sativic acids (0.07%) were used in the baking test and found to have no appreciable effect. Believing that the amount employed might have been rather small, 0.5% of the mixed sativic acids were used with the other ingredients in a baking test of the standard patent. This amount would have been equivalent to the oxidation of practically all the linolic acid present in a flour. The loaf volume was exactly the same as that of the standard loaf and hence the proof that the damaging action observed on oxidation is due to direct addition of oxygen to the double bonds of the free fatty acids.

Ether Extraction of Flour

Since the fat from fresh germ was not found to be injurious to the baking quality of a flour, another problem was to determine whether fat was necessary for good baking quality. Two flours of widely different character, one a 13.00% protein, strong, spring wheat patent; the other a 10.30% protein, red winter wheat patent with only fair gluten quality, were extracted with ethyl ether. The baking data on these flours is given in Table III. Curve 13 shows the result of ether

TABLE III

BAKING DATA ON ETHER-EXTRACTED FLOURS

Sample	Dough quality	Loaf volume 100% basis
Standard patent flour, 13% protein	Strong, elastic	100
Ether extracted standard patent flour, 13% protein	Strong, little short and tough	89
plus 1% germ fat	Strong, elastic	88
plus 1% flour fat	Strong, elastic	101
plus 0.03% sitosterol palmitate	Strong, little short	90
plus 1% germ fat plus 0.03% sitosterol palmitate	Strong, elastic	89
plus 0.027% non-sterol fraction of unsaponifiable matter from flour	Strong, elastic, little tough	90
plus 1% flour fat after removal of sitosterol palmitate	Strong, elastic	99
Standard red winter patent flour, 10.30% protein	Fair, elastic, slightly soft	95
Ether-extracted red winter patent flour, 10.30% protein	Fair, little short	82
plus 1% fat from same flour	Fair, elastic, slightly soft	95

extraction of the strong flour, (the same flour as was used in the first problem). Curve 13 shows stronger, tougher gluten characteristics and also a slower rate of hydration than the original unextracted patent as shown in curve 1. Both the hard spring and the red winter patents when ether extracted, exhibited the same tendency toward a tough, dead feeling in the handwashed glutens and in the ingredient dough. The resulting loaf volumes on both flours were far below standard. Ether extraction of flours in general makes a texture not quite so open as the unextracted flour, and, needless to say, in every case, improves the crumb color due to the removal of a large proportion of the pigments on extraction with this fat solvent. The Farinograph indicated an increase of somewhat less than 1% in absorption for the ether-extracted flours but it was found that an additional 2% absorption over the farinograph percentage gave the best feeling dough and a slightly larger loaf volume. Many variations of the baking procedure such as extra mixing, longer fermentation, additional lard, changes in the punching time, addition of various increments of po-

tassium bromate, additional sugar, and 1% malted wheat flour were tried in order to improve significantly the loaf volume of the ether-extracted flours but without success. It is interesting that even 6% lard failed to improve the loaf volume of the extracted sample.

Johnson (1928) found that the reducing sugar content and the diastatic activity of ether-extracted flours were higher than in the original flour. In our experiments, the gas produced, as determined on the Fermentograph, is given in Table II, and was found to be practically identical with that evolved by the original flour. Therefore, the decreased loaf volume was not due to lack of gas production.

The addition of flour fat to the ether-extracted flours brought the flours back to normal in every detail as determined by the Farinograph, hand-washed glutens, and as evidenced by their dough quality and the loaf volumes. Germ fat, however, when added to the ether-extracted flours, although it brought the dough quality back to normal in feeling, failed to increase the loaf volume. The gas produced by the ether extracted flour plus 1% germ fat was even higher than for the original flour or the ether-extracted flour with added flour fat as shown by the data in Table II. The low loaf volume of the ether-extracted flours plus germ fat cannot, therefore, be explained by decreased carbon dioxide production.

There must be some constituent or groups of compounds present in flour fat and not present in wheat germ fat which are vitally essential to good baking quality. It was thought that sitosterol palmitate, the structure of which was recently elucidated by Spielman (1933) and Dangoumau (1933), was the compound in question. Sitosterol palmitate was isolated from a concentrated acetone solution of the fat from the hard spring patent and was recrystallized several times from ethyl acetate. After the removal of the sitosterol palmitate, the acetone solution of the remaining fat was evaporated until free from acetone. Both the sitosterol palmitate (0.03%) and the fat (1%) from which this ester had been removed were added to the ether-extracted flour. It was found that, with the amounts used, sitosterol palmitate caused only a very slight improvement. The fat from which the ester was removed brought the ether-extracted flour almost but not quite back to normal. The non-sterol fraction of the unsaponifiable material from flour fat was also added to the ether-extracted flour in exactly the amount it occurs in the unextracted sample. It had no appreciable action.

Investigation of the glyceride structure and the unsaponifiable fraction of flour fat is already under way, and the differences between the lipids of patent flour and of the wheat embryo will be discussed in another paper.

Conclusions

Fresh wheat germ fat and most of its constituents, such as the unsaponifiable material, and simple triglycerides, such as tripalmitin, tristearin, trimyristin and triolein, have little or no effect on the behavior of a patent flour as shown by farinograph curves and baking tests.

Higher saturated fatty acids (which may occur in small amounts in any wheat product as a result of hydrolysis of the triglycerides) have only a very slight "shortening" effect on the flour-water curves. Unsaturated fatty acids (oleic, linolic, and linolenic) cause a decided change in the shape of the curves and produce "short," tough glutens when added to patent flour. These unsaturated acids, however, are only slightly detrimental to the baking quality of a flour. The bake is not harmed as much as one would expect from the feeling of the gluten.

Individual, unsaturated fatty acids influence a flour in direct correlation with their increasing number of double bonds.

Unsaturated fatty acids when exposed to oxygen have a significant damaging action on the baking quality of a flour. The dough feels dead, loses its elasticity and breaks easily. The loaf volume is decreased considerably. The action of these oxidized acids is identical with the result of extreme natural aging of flour. The unsaturated acids which result by progressive hydrolysis of glycerides on aging a flour (particularly at a relatively high moisture and temperature) do not do much harm to the baking quality until they become oxidized, either by oxidases present in flour or by the oxygen of the air. The oxidized products are peroxides rather than hydroxy acids.

Ether extraction injured the baking quality of both strong and weak flours examined during the past few crop years.

Flour fat brought the quality of the ether-extracted flour back to normal in every detail but germ fat did not, indicating that flour fat contains some constituent or group of compounds necessary for good baking quality which is absent in the germ lipids. The compound in question is not sitosterol palmitate nor is it contained in the non-sterol fraction of the unsaponifiable material of patent flour.

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CEREAL WORK OF THE AGRICULTURAL EXPERIMENT STATIONS

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Cereal work of the agricultural experiment stations has been an important field of investigations from the establishment of the stations. In the limits of time for one address, the subject might be approached and developed from any one of many angles. I have been somewhat perplexed as to the best way to participate in your program and not deal in a feeble way with topics which are to be specifically and ably presented by outstanding research workers who will address you later in your sessions. As an administrative officer contacting and participating in the general, and, to some extent, in the detailed plans of the work of the State experiment stations and of the Department of Agriculture, I shall deal with the subject under consideration from the angle of organization, relationships and interrelationships, problems, objectives, and planning, and with only secondary emphasis on technical aspects.

The cereal work of the State agricultural experiment stations is so closely related and involved with the cereal work of the Federal Department of Agriculture that a brief statement of the organization "set-up" and relationships is essential at this point. While there were a few State experiment stations prior to 1887, the present agricultural experiment stations in the 48 States were established in accordance with the Federal Hatch Act, known as the experiment station act, of 1887. By this act the Federal Government inaugurated a policy of aiding the individual States in establishing and maintaining agricultural experiment stations for the purpose of conducting such researches or experiments bearing directly on the agricultural industry of the United States as may in each case be deemed advisable, having due regard for the varying conditions and needs of the respective States and Territories. The original grant of $15,000 to each State has been increased by supplemental legislation to a total of $90,000 in Federal-grant funds to each State annually. There is no requirement of the States to match the Federal-grant funds, although the later grants were predicated upon the States having been liberal in their support of the experiment station work. As an average for the 48 States, the financial contributions from funds other than the Federal-grant funds amount to from $2 to $3 from all State sources to each $1 of the Federal grants. In 1931 the ratio was $3 of State funds to $1 of Federal funds.

In 1934 it was approximately $2.20 to $1. In addition, the State is expected to provide most of the physical plant facilities.

On the other side of the picture we have the Federal Department of Agriculture with its direct appropriations and direct responsibility from Congress for research and experimentation with cereals, as well as with other agricultural problems. A close relationship in the work of the two agencies was recognized when the experiment station Act of 1887 was passed and authority was given the Secretary of Agriculture to participate with the State agencies through suggestions as to lines of work to be conducted under the Federal-grant funds. Later, through the annual appropriation acts, the Secretary of Agriculture has been charged with a certain amount of responsibility for coordination of the work of the agricultural experiment stations and that of the Department. Through standing committees, policy agreements, and in other ways, the Department and its bureaus and the State experiment stations have evolved working arrangements which provide for a pooling of resources and efforts.

In line with this general set-up and policy, I should class the present cereal work of the Bureau of Plant Industry in the Department, for example, as 100 percent in cooperation with the work of the State agricultural experiment stations. Even the laboratory work in Washington and the plot work at the Arlington Farm and elsewhere near Washington are a part of the National-State program. Plant introductions from foreign countries are tested by the Department and are appraised as to their value or suitability for different sections of the country. On this basis they are distributed, through cooperative arrangement, throughout the country. On the other hand, materials which show promise in any of the States may be assembled and tested by the Department to be redistributed to other States and incorporated in the cereal improvement program, if they possess merit to warrant such distribution.

I wish to make clear here that any broad discussion of the cereal work of either the State agricultural experiment stations or of the Department of Agriculture should be understood to include both agencies. No attempt, therefore, is made in this paper to fairly assign proper credit and responsibility to these agencies in each individual case referred to.

The Office of Experiment Stations might be termed an intermediate agency working with both groups. The Office and its staff acts for the Secretary of Agriculture in administration of the Federal-grant funds to the States, and, to an increasing extent, acts for the State experiment stations in arranging cooperation and coordination of their research with that of the bureaus of the Department.

In considering the cereal work of the agricultural experiment stations and the program under way or to be developed, one needs first have in mind at least a general picture of the whole field of cereal production and consumption, with its manifold problems and its relationship to agriculture and related industries. In this picture perhaps the element of first importance is summed up in the old statement, that "bread is the staff of life." It is my understanding that in 1931, for example, some 2400 mills were busy manufacturing flour, that nearly 18,000 baking establishments were in operation, and that the flour and other mill product output was valued at nearly 600 million dollars. The question of how we can have better wheat and bread at prices fair alike to producer, processor, and consumer is thus clearly important. If we should inquire into the question of the production and consumption of cereal feeds we should no doubt have a somewhat similar picture. Likewise, if we examined other uses of cereal products we would find the field of interest still further extended.

On the production side, the December 1, 1934, estimates of the Bureau of Agricultural Economics show a total farm value of all the cereals estimated at nearly 2 billion dollars, about 41 percent of the total value of crop production. Of this total, wheat, in its smallest crop since 1890, was estimated in value at about 432 million dollars, harvested from over 42 million acres. Of equal importance is the fact that the 42 or more millions of acres harvested were distributed over perhaps more than a million farms in all parts of the United States,[1] and that the cash received from sale of wheat and other cereals amounted to over 11 percent of the total cash income of farmers from the sale of all farm products in 1934.

In addition to the main picture, those responsible for the cereal work have much to keep in mind as to cereals in relation to the cropping system from Maine to California, and from Washington to Florida. The small farmer may need a cash income and because of location or some other factor, some cereal crop may afford his only opportunity to secure it. Sound farm management and business operation of the farm, including the items of labor and machinery, may argue for or against the inclusion of cereals, and the farmer or the community looks to the experiment stations for an answer to this problem. These factors and others combine to make up a relationship of the cereal work to agriculture and to the people engaged in agriculture and in the use of cereals and cereal products, which is rather complex, far reaching, and important in the everyday life of our people.

With the foregoing sketch of the organization, relationships, and broad field involved, one might well speculate with interest as to the way in which the research program and the individual researches are

[1] 1930 census.

decided upon and organized. In answer to this question, I should outline as of first importance, and fundamental, the continuous coordinated Federal-State effort to improve and make available what might be termed basic material through plant introduction, breeding, selection, and adequate testing. In earlier days this perhaps was not of so much importance. Under present and future conditions, our ability to maintain economy in production and at the same time adjust quality to the desires or needs of manufacturers and consumers may depend upon the basic material available for cereal work in plant improvement and adjustment. There has been rather general agreement on this point for a number of years, and during the present year, under the leadership of the Department, in cooperation with the 48 State stations, a survey and study is being made to develop a usable, available record of valuable plant material, call it "germ plasm" if you will.

The specific problems for research, unfortunately perhaps, are most often determined by shortcomings or troubles in connection with prevailing practice. Plant diseases and insect problems may suddenly become limiting factors in the production of a cereal crop. The enemy is at the door. The problem is determined. A change in mechanical equipment, such as the introduction of the small combine harvester, may create new problems for the cereal worker in developing grains which will ripen in the field without shattering or lodging. A slight change in the economics of production, distribution, and marketing may so narrow the margin of profitable production in certain areas that the cereal research worker is called upon to develop improved varieties or strains, or new methods of culture which will save the industry in the locality in question. The specific problem may be improvement of winter hardiness to increase yield, development of drought resistance, adaptation to specific soil conditions, and in time of ripening to avoid frost or some other similar problem to provide the margin necessary for the production area to continue.

From the utilization side, questions of quality, protein content, milling and baking quality, and vitamin content create an additional set of problems for the plant breeder aside from those mentioned as applying to yield and economy of production. The selection and character of these problems are influenced to a considerable extent by the progress in the more fundamental research related to milling and baking, vitamins, nutrition, and various uses of cereal products. For example, the fact that the starch in wheat determines to an important degree the characteristics of flour naturally has led to additional more specific investigations on wheat starch, and the relation of starch to bread baking may be later the subject of other specific research, not only of this kind but on selection, breeding, and handling to bring the

wheat produced up to the quality standards as they may be established from time to time.

In suggesting for my discussion the question of how projects are chosen, the chairman of your Program Committee perhaps had in mind more specifically the administrative procedure. I have purposely approached the answer from the point of view of what might be termed the need or demand for information. This need is continuously in excess of the experiment stations' man power and funds to supply. This fact makes difficult the planning and maintenance of research on fundamental principles of, say, milling and baking, vitamins, fermentation, and plant improvement, notwithstanding the ultimate importance of the findings from such fundamental research.

In the administration and use of the Federal funds granted to the States for agricultural research, the State station director and his staff initiate the proposals for the research. The Federal Acts provide, as stated in the beginning of this paper, that such research shall bear directly on the agricultural industry of the United States, but with due regard to the varying conditions and needs of the respective States and Territories. The project proposals for the most part are carefully outlined in writing and submitted to the Office of Experiment Stations for review and suggestions. There perhaps is some misunderstanding as to the purpose of such Federal participation. We think of it as participation and not as control or domination. Our main objective throughout is to ascertain (1) whether the problem suggested for study is consistent with the provisions of the respective Federal Acts and merits the expenditures proposed; (2) whether the information sought is available at some other station or in the Department, or can be expected within reasonable time from research under way elsewhere; (3) whether the proposed procedure, leadership, equipment, and assignment of funds are reasonably adequate to the undertaking proposed; and (4) whether there is opportunity for coordination or cooperation with research or research workers in the same or closely related subjects elsewhere. Through correspondence or conference with the director and his research workers, these points are agreed upon before a project is approved and the work initiated.

The broad aim of the many lines of research with cereals carried on as projects in the experiment stations, extensively in cooperation with the United States Department of Agriculture, is the production of high-yielding grains, resistant to or evading cold, drought, diseases, and insects, or other adverse environmental factors, and possessing those suitable or superior technological qualities desired by the processor—miller, baker, foods manufacturer, or maltster—the consumer and the livestock feeder. The many factors which must be dealt with

in the quest for better cereal products are considered in numerous projects in which the cereal chemists cooperate with the agronomists, plant physiologists, pathologists, economists, home economists, and agricultural engineers.

Variety or strain characteristics and their improvement by pure-line selection or hybridization, or replacement by superior grains introduced from other countries lead to many studies involving the cereal chemist. The influence of regional or seasonal climatic conditions, the cropping system, soil type, soil fertility and fertilizer practice, dry land *v.* irrigation farming, and cultural operations including seed-bed preparation, seed treatments, various planting practices, and cultivation in early growth, all have their bearing on the final products, and the chemists' cooperation is important. Many problems for cereal chemistry have centered around harvesting practices and their effects, for example, stage of growth, binder *v.* combine, effect of frost and freezing in the shock, stacking unthreshed grain, threshing practices, and storage and handling of combined or threshed grain.

Numerous additional problems for the cereal chemist arise when the grain leaves the production phases and enters commercial movement. The importance of the grading factor as a chemical problem is quite evident. As regards grading it has been pointed out; in U. S. Department of Agriculture Bulletin 1187, page 12, that "Equitable standards should truly reflect or indicate relative commercial values including differences in quality due to climate or geographical location of production, and the relationship existing between the various physical and chemical properties of wheat and its milling and baking quality." Various questions relating to keeping quality in transportation and storage also present themselves for consideration by the chemist.

Beyond the production and marketing phases of the cereal industry are met the many problems, perhaps of more direct concern to the cereal chemists, relating to milling operation, flour quality, bread making, and by-products and their utilization, and nutrition. Results of research in most of these technical problems are to be treated in detail by others on the program. I shall therefore impose upon you only to discuss a few lines of such research in a somewhat general way.

Soft wheat flour baking studies at the experiment stations, for example, have followed two different lines. On the one hand has been the work of station chemists as members of your organization in developing and improving standard baking tests to be used in judging wheat flours. There is no need for me to review the contributions from the experiment stations in wheat growing sections of the country, such as Kansas, Nebraska, Minnesota, Illinois, and others, for such contri-

butions represent the organized work of your association and are reported in your official organ, *Cereal Chemistry*.

The other line of work is more local in character—the testing of flour from locally grown wheat to determine its special characteristics for baked products and if necessary to determine needed changes in ingredients, manipulation, and other features of the bread making process. To such work the home economics specialists have made helpful contributions. An illustration of this is a study of cake and biscuit-making qualities of flours from Maryland wheats, recently published by the Maryland Station as Bulletin No. 360. In this study an attempt was made to throw light upon: (1) The cake-making qualities of flour from Maryland wheat in comparison with those of commercial cake flours, (2) the effect upon cake quality of differences in protein content within the range of variability ordinarily presented by flour from the local crop, (3) the effect of patent milling and bleaching upon cakes made from these flours, and (4) biscuit-making qualities of flour from local wheat in comparison with those of commercial general purpose flour.

It was found that certain milling products of the Maryland grown wheat were adapted to certain kinds of cake and others to cake of a different type. With these findings as a basis, recipes especially adapted to the Maryland flour under test were developed and published. This study is representative of practical or more strictly service studies carried on in different parts of the country.

The baking qualities of soft-wheat flours have been under investigation by the Illinois Station for several years. The leader in this project, Sybil Woodruff, says: "The particular way in which our studies differ from other soft-wheat studies is that we have used throughout, single varieties of certified wheat. For the past four years one of the commercial mills in the State has milled our wheat according to accepted practices. Previously the wheats had been milled in experimental laboratories. We have records over several years now on flours milled from these single varieties of wheat. The Department of Agronomy at the University of Illinois has cooperated to the extent of selecting for study varieties which have good agronomic possibilities in the State. The Southern Illinois Millers' Association cooperates to the extent of providing milling facilities; their advice and interest in the project have also been of great value. Flour grades, degrees of granulation and effects of bleaching have been studied in the course of the work." This is a good example of effective cooperation of various agencies and interests. If time would permit, a statement relative to the Illinois work on wheat, corn, and other cereal starches would be of interest, I am sure.

Since the research work on starch at the Minnesota Station is to be reported on at this meeting by Dr. C. H. Bailey, and that at the North Dakota Station by Dr. C. E. Mangels, I merely direct attention to their researches as of high significance in the work of the experiment stations. I regret that Dr. Bailey and Dr. Mangels are not to report also on other projects which go to make up their respective programs of special interest to your membership. The Minnesota Station has a group of cereal projects which include Biochemistry of Milling and Baking; Research on the Strength of Wheat Flour; Varietal Improvement in Winter Wheat, including Milling and Baking Qualities and Winter Hardiness; and Investigations of Proposed Official Methods of Analysis. In the list of North Dakota projects are studies on the Quality or Suitability of Wheats for the Manufacture of Food Products; Factors Which Influence the Protein Content of Hard Spring Wheat; and Studies of the Fatty Constituents of Wheat and Wheat Products, and Their Relation to the Technical Value of Flour and Other Mill Products, including the Study of Physical and Chemical Properties of Starch from Different Types of Wheat, which is listed on your program for report by Dr. Mangels.

I note that Dr. C. O. Swanson, of the Kansas Experiment Station, another of your distinguished members, is on your program for a report upon his research as to "Varietal Factors in Quality as Revealed by the Recording Dough Mixer," and that Dr. E. B. Working will present another phase of the Kansas studies. The program of projects at the Kansas Station, as a whole, seems to me of special interest and significance to the members of this association, enlisting as it does the cooperation of the cereal chemist with that of the agronomist and the plant breeder in study of problems of the producer, the processor, and the consumer of cereals.

As you well know, too, the Nebraska and the Montana Stations have undertaken a considerable amount of work of particular interest to the cereal chemist. I am glad to note that Dr. Blish is on your program.

Outside the major Wheat Belt the research programs of the stations in the line of cereal chemistry are less extensive. However, at the Arizona Station, the Idaho Station, the Michigan Station, the Pennsylvania Station, the Utah Station, and perhaps others, such research of real merit is under way. Even your liberal assignment of time to me does not permit of further discussion on this point.

The experiment stations have figured prominently in vitamin research. Osborne and Mendel at the Connecticut New Haven Station might be said to be codiscoverers with Sir Frederick Gowland Hopkins in England of the original water-soluble vitamin B. McCollum and

his associates at the Wisconsin Station furnished further proof of the existence of this vitamin, and in both the Connecticut and Wisconsin laboratories the existence of another vitamin, A, was demonstrated almost simultaneously. It is of interest that the work at both of these stations which led to the discoveries of vitamins A and B was concerned with the chemistry and nutritive properties of cereal grains.

It was Mitchell at the Illinois Station who in 1919 first seriously challenged the belief that only one substance was involved in vitamin B. (At present there seem to be no less than five or six separate vitamins in this group.) Salmon at the Alabama Station, Hunt at the Ohio Station, Hogan at the Missouri Station, and their associates were among those to contribute proof that the old vitamin B is made up of at least two factors.

To complete the vitamin alphabet in its relation to experiment station work, I might mention in passing that the Wisconsin, Minnesota, Illinois, and Indiana Stations made early contributions to knowledge concerning the unlike requirements of various animal species for vitamin C; that the discovery that natural foods can be enriched with vitamin D was made at the Wisconsin Station; and that the existence of vitamin E was first demonstrated practically simultaneously at the California and Arkansas Stations.

With the experiment stations interested in vitamin research from the start, it is not surprising that they have played a prominent part in the particular phase of vitamin studies in which as cereal chemists you are presumably most interested—the vitamin content of cereals. Considering only the staple cereal crops wheat and corn, it is essential to know what vitamins are present in significant amounts; in what part of the cereal grain they are located, how the content of any particular vitamin is affected by various factors such as variety, soils and fertilizers, and manipulative processes during milling, and others; what the possibilities are of preparing vitamin concentrates from cereals, and finally to what extent certain vitamins in cereal feeds, or foods can be transferred to animal food. There is a type of fundamental vitamin research, moreover, in which the cereal grains or their by-products serve in a sense as reagents in the effort to isolate and identify the vitamins themselves, and in the study of vitamin physiology. There is time here only to sketch briefly two or three lines of work at the experiment stations in this broad field.

The distribution of vitamin B in the various parts of the cereal grains was made the subject of early study at the Connecticut Station at New Haven, and later an extension of this work was carried on at the Illinois Station. In wheat vitamin B was found to be dispersed through the whole kernel, but with the greater part concentrated in

the germ and bran. In corn, however, the vitamin was found to be located almost exclusively in the germ, and in rice in the germ and bran or polishings.

With the differentiation of vitamin G from vitamin B, the Illinois Station extended its observations to the location of this part of the old vitamin B in cereal grains. Its distribution in corn is of particular interest on account of association of pellagra. The Illinois Station found that all of the vitamin G in the corn kernel is in the germ and that consequently when degerminated corn meal makes up the bulk of the diet a deficiency in this vitamin is bound to occur.

With the cereal grains as outstanding sources of the B vitamins, new uses of that part of the grain commonly discarded in the milling process are suggested—a problem for cereal chemists because of the tendency of the germ to become rancid and of vitamin B extracts from any source to lose their activity on manipulative treatment. Difficulty in separating the vitamins is also a problem if a concentrated source of only one is desired. From the standpoint of nutrition, successful small scale packaging at low cost to the consumer of such products as rice polishings and wheat embryo would be of great value. Sure of the Arkansas Station, for a long time has been interested in the preparation from rice polishings of a concentrate of vitamin B suitable for use in maternal and infant feeding and has succeeded in preparing a highly active concentrate which gives promise of being satisfactory as a vitamin B (and G) concentrate for human use.

The connection between vitamin A and the yellow pigment carotene was first pointed out in studies on yellow corn by Steenbock and his associates at the Wisconsin Station. This was the beginning of extensive research at the experiment stations and elsewhere, which finally resulted in the proof that carotene in materials of plant origin is the precursor of vitamin A in material of animal origin. A whole morning might be spent in discussing experiment station research on the many problems connected with the vitamin A (or carotene) content of yellow corn—genetic and varietal studies at the Indiana, Texas, New Jersey, and Kansas Stations; studies at the Illinois Station on the location of the vitamin A in the corn kernel and its milling products; studies at the Missouri Station on the problems of increasing the vitamin A content and color of egg yolk by the use of yellow corn in poultry feed, and at the Illinois Station on the similar problem of increasing the color index and vitamin A content of butterfat by feeding highly pigmented corn to dairy cattle.

Mention of vitamin E recalls the fact that a cereal product, wheat germ oil, is perhaps the richest known source of the vitamin and that most of the research on vitamin E has been done at the California Station.

There is probably no need of recalling to cereal chemists th brilliant work of Steenbock at the Wisconsin Station on the synthesis of vitamin D in natural foods by irradiation, for the cereal industries were, I think, the first to avail themselves of the Wisconsin Alumni Research Foundation licensing system for vitamin D and introduce vitamin D into bread and cereal products.

The work referred to by no means covers the list of experiment station research projects dealing with vitamins in cereals. Year by year, with improvements in technique and increased knowledge of the multiplicity of factors involved in successful nutrition, vitamin studies become more complex. Even such a seemingly simple problem as the relative nutritive value of yellow and white corn cannot be solved completely by assays of vitamin A content. A recently completed investigation at the Pennsylvania Station on this problem took into consideration not only the relative efficiency of white and yellow corn in providing the requirements of maintenance and growth of animals, but also the composition of the body increases and the exact use made of the food energy in both cases. Metabolism and body-analysis experiments conducted on paired rats receiving presumably complete rations differing only in that one contained white corn and the other yellow, indicated that the yellow-corn ration definitely excelled the white-corn ration only in palatability and in gain produced in body weight, while the white-corn ration excelled in digestibility of food energy. The experiments were continued for only 13 weeks and of course do not prove that vitamin A, which is present in the yellow corn and not in the white, is not essential. They do emphasize, however, the need of more knowledge concerning the exact nutritive value of food products, in this case cereals. The fact that yellow corn is superior to white corn in its contribution to the vitamin A content of the diet does not mean that it is of superior nutritive value in every respect.

Many perplexing problems in regard to yeast, enzymes, and fermentation, in their various relations to other chemical and physical factors involved in bread-making have been considered extensively at the experiment stations. Although there are no station projects devoted solely to yeast or fermentation, certain phases of the subject are dealt with in other cereal chemistry projects; as, for example, in a Minnesota Station project on biochemistry of milling and baking, which includes a study of the fundamental phenomena involved in dough fermentation and baking, and one on strength of wheat flour, which also includes studies of enzymes, especially diastatic activity and protoclastic activity in relation to flour strength and baking quality. The North Dakota Station has a project on the quality or

suitability of wheat for the manufacture of food products, which includes studies of the factors known to bakers as "stability" and "fermentation tolerance" of dough. A Montana Station project dealing with biochemical factors affecting the quality of wheat and flour for milling purposes considers the relation of diastatic activity and other factors to bread making and flour strength.

A Nebraska Station project, Enzymes of Wheat and Flour as Related to Flour Grade and Baking Characteristics, is worthy of special mention. This project embraces a study of the more important flour enzymes from the viewpoint of improved methods of identification, and their relation to some of the more important flour properties. Special gasometric and colorimetric methods are being developed for quantitative estimation of diastase, catalase, cytase, and related enzymes in wheat products, and the methods applied to flours of varying grades and qualities.

Although the experiment stations have done more work on wheat of direct interest to you as cereal chemists than on other cereals, there are important studies under way especially on corn and on barley. The chemical composition of corn was one of the earliest and most important subjects of investigation by the Department of Agriculture and the Massachusetts Experiment Station. No less significant is the later work of Wisconsin, New Jersey, and other experiment stations indicating the superiority of yellow corn over white corn. The study of the use of corn as a human food, and the effect of cooking on corn and corn starch, involving the difficult problem of isolating normal unchanged starch from corn, in which the Illinois Station is now engaged, is also a thorough-going piece of research which promises developments of great scientific and practical value. The cooperative investigations on corn improvement, in which the Department is cooperating with 20 or more stations, is one of the most effective researches under way. Many other examples might be given of station work dealing effectively with the improved production, processing, and use of corn.

Excellent studies have been under way for a number of years relative to improvement of barleys under the leadership of the Department in cooperation with State stations. Within the past few years special studies have been undertaken to find varieties or strains better suited to malting and pearling. The Wisconsin, Michigan, North Dakota, Minnesota, Oregon, and other stations are cooperating with the Department in these studies.

The cereal chemist plays an important part in the experiment station work with cereals as with other products. In some of the problems the chemist working alone may find the solution. I wish to

stress, however, the important fact that many of the varied problems of cereal production, processing, and use call for the united effort of many scientific specialists, as well as cooperation of the commercial interests concerned.

Before closing I should like to comment briefly on the important and somewhat difficult problem of keeping the research worker and the public informed of research under way, and especially of the results secured.

Those who participated in the discussions at the time the Experiment Station Act was passed in 1887 realized the importance of this question and made several provisions to help meet the need as they saw it. The Hatch Act provides that bulletins or reports of progress shall be published by the stations, that a copy shall be furnished to newspapers, and that such bulletins or reports shall be transmitted in the mails of the United States free of charge for postage, under such regulations as the Postmaster General may prescribe. The cost of printing and distributing the results were specified as a proper charge against the Hatch grant fund. In addition, it was the joint conclusion of the State and Federal workers at that time that there should be some way of bringing to the attention of all workers, in brief form, the published results of agricultural research. Accordingly, the Experiment Station Record, with which you are familiar, was established and the first number issued in September 1889. The Record has been continued to date.

Aside from the bulletins, circulars, leaflets, etc., published by the State stations and the Department, there is a large number of scientific journals which publish papers of significance to the research workers of the agricultural experiment stations. I could not say just how many such journals, but I have recently looked over a list of some 63. The records of the Office of Experiment Stations show that 1,373 articles were contributed by the State experiment stations to outside journals in the fiscal year 1934, in addition to 90 articles published in the Journal of Agricultural Research, and 842 bulletins, circulars, and other publications in the regular series. A more complete picture is expressed by the fact that approximately 88,000 periodicals and 10,000 books were available for examination as to agricultural material for abstracting in the Experiment Station Record in 1934. From this number about 29,000 were called to the attention of specialists on the Record staff, and of these about 6,800 were selected for review in the space allotted to the Record. With this great mass of material annually, few research workers can hope to have library facilities and time to examine the original articles. The object of the Experiment

Station Record, as of other abstract journals, is to bring to attention as promptly as possible the more outstanding contributions.

The question of publication of the results of station research is now under consideration by a special committee appointed by the Experiment Station Section of the National Association of Land Grant Colleges and Universities. There is need for continuing thought along this line to insure prompt publication of new proven facts from research, to minimize the amount of published statements under the title of research which do not contain new proven facts of significance, to direct the various types of publications into channels where they will serve their major purpose, and to keep abstracting service abreast of the task to be performed in this field.

ON THE EXISTENCE OF POWERFUL BUT LATENT PROTEOLYTIC ENZYMES IN WHEAT FLOUR

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Introduction

Recently the author developed and experimentally established a theory relative to the fundamental nature of bromate action and analogous actions. Details concerning the experimental aspects of the theory are given in two recent papers by the author (see Jørgensen, 1935 and 1935a).

Briefly, the theory is that $KBrO_3$ paralyzes (more or less completely) the proteinases [1] of the wheat flour. When these proteinases are paralyzed, the break-down of the proteins of the dough diminishes. As a result, the gas-retaining capacity of the dough membranes increases; in other words, baking strength will increase.

In this manuscript only the more important arguments for the theory will be mentioned, *viz.:* (1) The activity of many proteinases from tissues or cells, for instance, papain, bromelin (the proteinase of raw pineapple juice), and liver proteinases, is strongly reduced (depressed) by $KBrO_3$; (2) $KClO_3$, which does not improve the baking strength of wheat flour, does not reduce (depress) the activity of the proteinases just mentioned; (3) it can be shown that the activity of the proteinases of wheat malt and wheat germ is reduced (depressed) by $KBrO_3$ (but not by $KClO_3$); (4) ascorbic acid, known to be able to reduce (depress) the activity of plant-proteinases of the papain-type, has been found to be a good improver of the baking strength of wheat flour.[2]

As far as the author is able to judge, on the basis of communications kindly sent to him, his theory of the nature of bromate action has found general approval amongst cereal chemists. At the same time, however, it was pointed out to the author that certain facts do not appear to be in accordance with the theory. Special objections were raised which can be summed up as follows:

When the very small amounts of proteinases present in flour are con-

[1] The term "proteinases" is used in this paper to designate the proteinases which attack the native proteins, to distinguish from the "peptidases," which only attack peptides.
[2] Patent applied for in U. S. A. by the author.

sidered, how can one believe that the strong influence of bromate on baking strength is really due to a reducing (depressing) effect of bromate on the activity of flour-proteinases?

It is true that the amount of proteinases in wheat flour is generally believed to be small and of no great importance. (Reference can here be made to Hesse's recent review (Hesse, 1935) dealing *inter alia* with several papers published in "Cereal Chemistry" on this subject.)

On the basis of the experiments described below, the author, in contrast to the prevailing view, has come to the conclusion that *wheat flour is a material which contains powerful proteinases. Usually, however, these powerful proteinases do not manifest their existence because they lack suitable activators. In the presence of a suitable activator, glutathione, for instance, the great power of the proteinases of the wheat flour manifests itself very clearly.*

Realizing that flour-proteinases when activated are very powerful and *that an activation certainly takes place during the fermentation time (because yeast is an important source of substances which are able to activate flour proteinases)*, one can no longer wonder that substances such as $KBrO_3$, which are able to depress the proteinase-activity, exhibit a strong influence on baking strength. This is the answer to the question set forth above.

Materials and Methods Used

Flour. The flour used in the experiments was milled from a lot of No. 1 Manitoba wheat of the following composition. When used in the experiments, the flour had been stored for three weeks.

Moisture, %	15.1
Crude protein, %	13.50
Ash, %	.48
Acidity, pH	5.95
Diastatic activity	115 [3]

Yeast. The yeast used for the preparation of yeast water as well as for the baking tests was ordinary Danish bakers' yeast manufactured by De Danske Spritfabrikker, Ltd., Copenhagen.

Glutathione. Glutathione was employed in some of the experiments to be described. This biologically important substance was discovered by Hopkins (1921) and shown by him to be an important constituent of yeast. Yeast is still the principal raw material for the preparation of glutathione which, by the way, is found in a very large number of plant and animal tissues. Later the constitution of the substance was ascertained (see Hopkins, 1929); glutathione being a tripeptide, $C_{10}H_{17}N_3SO_6$, containing glycine, glutamic acid and cysteine. The SH-group contained in the molecule is responsible for the

[3] Milligrams of anhydrous maltose produced by digestion of 10 g. of flour at 27° C. for one hour.

nitroprusside reaction given by glutathione. The glutathione preparation used in the present investigation was obtained from The British Drug Houses, Ltd., London. An elementary analysis of this preparation [4] gave the following satisfying results:

	C %	H %	N %	S %
Average of 2 analyses	38.97	5.61	13.34	10.31
Calculated for $C_{10}H_{17}N_3SO_6$	39.09	5.54	13.68	10.42

Yeast water. Yeast water was prepared as follows: One part of bakers' yeast was thoroughly mixed with one part of tap water, heated

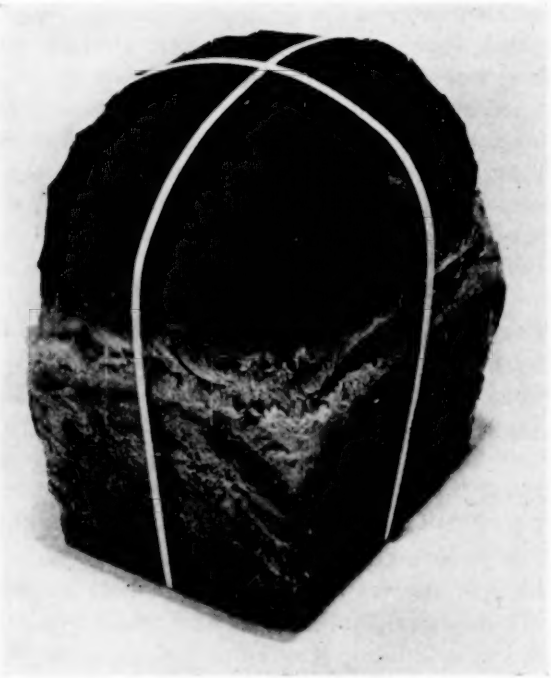

Fig. 1. The measure of a loaf.

to boiling and boiled for ten minutes. The liquid was then filtered until clear. The yeast water was always freshly prepared when used.

Farinograms. Farinograms were recorded using the Brabander farinograph. As this apparatus is so well known, a detailed description appears unnecessary.

Baking-tests. Baking tests were made in accordance with the

[4] Carried out by Laboratorium für Mikrochemie, Dr. Carl Tiedcke, Hamburg 19, Germany.

standard-method of the Danish Home-Grown Wheat Committee (see Jørgensen, 1933). Dough composition: Flour 560 g., salt 7 g., sugar 5.6 g., and yeast 5 g. The nature and amount of liquid used is indicated below for each individual case. Dough temperature, 30° C. The baking procedure, which is a fixed one, is as follows: First punch, 90 minutes after mixing; second punch, 30 minutes after the first punch. After the second punch the dough is fermented 30 minutes. A 750 g. piece of dough is scaled off, moulded, placed in a tin of standard dimensions and proofed for 70 minutes. Total dough time, 220 minutes. Finally the loaf is baked for about 45 minutes at a temperature of about 230° C. A rough measure of the volume of the finished loaf is obtained when determining what is called the "measure of the loaf." The loaf is measured around its length and breadth, as indicated by Figure 1, and the two figures added together. The sum of these two figures (expressed in inches) is the "measure of the loaf." For example, the greatest circumference in one direction was 22¼ inches, while the greatest circumference in the other direction was 19½ inches, "measure of the loaf" was 41¾ inches.

Experimental Results

During Willstätter and his co-workers' famous investigations on enzymes, carried out about 10 years ago, the idea that nature prepares organic substances possessing the property of being able to activate plant-proteinases, arose for the first time (Willstätter, Grassmann, and Ambros, 1926).

The existence of such activators, however, was not ascertained before the work of Ambros and Harteneck (1928, 1929). Inspired by Hopkins' discovery of the ubiquity of glutathione in the organic nature, Grassmann finally succeeded in proving that glutathione at least is one of the substances which nature uses for the activation of plant-proteinases of the papain-type (Grassmann *et al.*, 1930, 1931).

The author (Jørgensen, 1935b), as the result of some experiments with dried yeast some months ago, conceived the idea of examining the influence of glutathione on wheat flour doughs.

As mentioned above, wheat flour proteinases, in their behaviour against oxydants, very much resemble the papain-group of proteinases. It should, therefore, be of interest to see whether wheat flour proteinases in their behaviour against glutathione also resemble the papain-group of proteinases.

In Experiments 1 and 2 described below, the very striking results of the addition of glutathione to dough are reported.

Experiment 1

Two doughs, A and B, were made from the flour previously described. The composition of the doughs follows:

	A	B
Flour, *grams*	100	100
Distilled water, *cc.*	60	60
Glutathione, *milligrams*	None	100

The temperature of the doughs was room temperature (20° C.). The two doughs were rolled up immediately after mixing and placed side by side on a wooden plate, which was then placed in a room having a temperature of 30° C. A few minutes later it was obvious that the gluten in dough B had lost its strength and after half an hour the situation was as shown in Figure 2.

Fig. 2.

A
Without glutathione

B
With glutathione

As glutathione in itself possesses no proteolytic activity at all, the only acceptable explanation of the phenomenon must be that glutathione activated the proteinases of the flour. The consistency of dough B, as thown in Figure 2, was very much like that of Camembert cheese; the gluten had almost completely lost its strength.

Experiment 2

(*a*) The influence of glutathione on the consistency of the gluten, as revealed in Experiment 1, was also demonstrated by means of the Farinograph. Figure 3 shows a farinogram record of the flour used in all these experiments. The dough was made from 300 g. of flour and 188 cc. of tap water. The temperature of the flour, water, and dough was 30° C.

(*b*) This experiment was a duplicate of Experiment 2 (*a*), the only difference being that when the dough had been mixed for five minutes in the dough-mixer 300 mgs. of glutathione were strewn into the dough without interrupting the mixing procedure. The moment at which glutathione was added (five minutes after the start of dough-mixing)

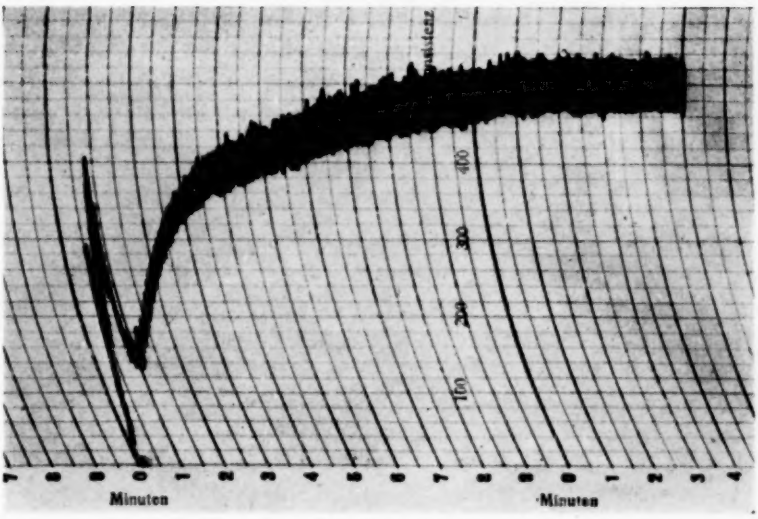

Fig. 3. Normal farinogram record of the flour used (see Experiment 2 (*a*)).

is indicated by means of an arrow in Figure 4. It will be seen that about 2 minutes after the addition of the glutathione the elasticity and strength of the dough was spoiled.

Experiments as those just described (Experiments 1 and 2) clearly show that wheat flour contains powerful proteolytic enzymes which, however, are usually latent.

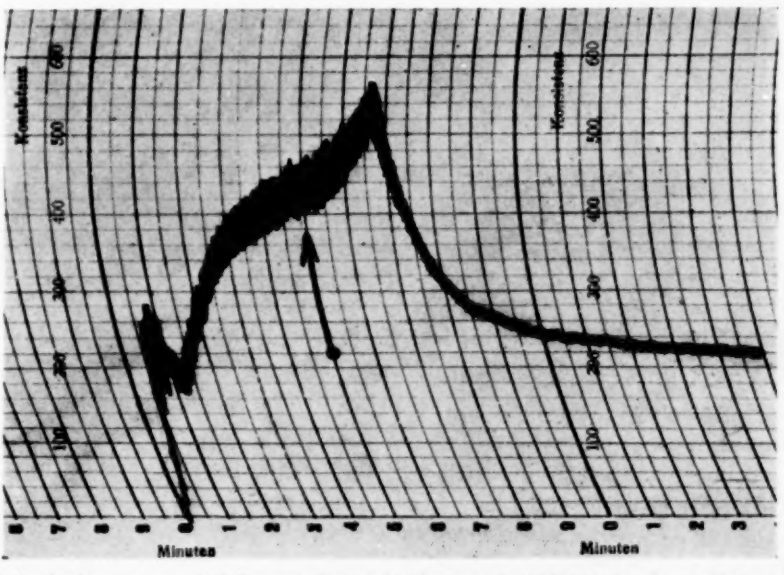

Fig. 4. Farinogram record of the same flour as in Figure 3, glutathione having been added at the time indicated by the arrow (see Experiment 2 (*b*)).

All the flours which the author has hitherto examined with respect to their behaviour against glutathione (including flour milled from weak Danish wheat) have shown the same property as the flour used in Experiments 1 and 2, namely, that their proteinases were strongly activated by glutathione.

Experiment 3

The activating influence of glutathione on the proteinases of wheat flour may, of course, also be demonstrated by means of baking tests. Using the same flour as before, two baking tests were made according to the standard method previously described. The amount of water (tap water) used for each dough was 352 cc. The first dough (marked "W") got no extra additions. The second dough (marked "GSH") got an addition of 100 mgs. of glutathione. Figure 5 shows cross-sections of the finished loaves. The bad crumb and the small volume produced by the addition of glutathione appear clearly in Figure 5. The "measures" of the loaves were for "W" 42¼ inches; and for "GSH" 39⅛ inches.

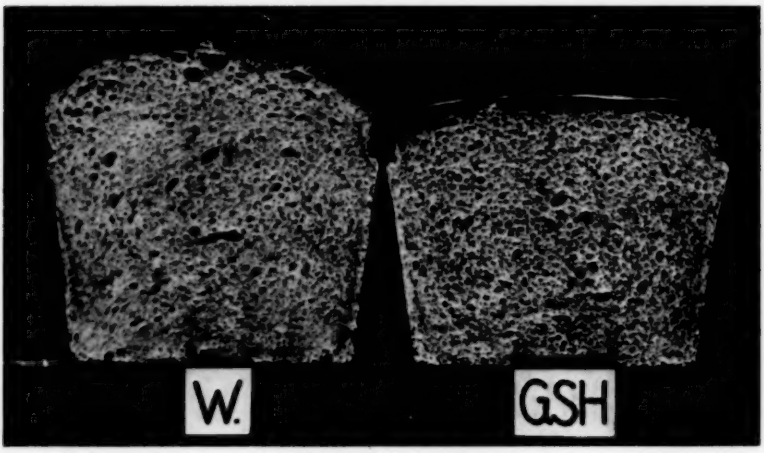

Fig. 5. Loaves made without ("W") and with ("GSH") addition of glutathione.

Experiment 4

Glutathione being a rather expensive substance the author examined yeast-water (which is the raw-material Hopkins used for the preparation of glutathione) to see if it could produce effects similar to those produced by glutathione when acting on wheat flour doughs. This proved to be the case. The farinogram shown as Figure 6 was recorded using the same flour as in Experiment 2 (a) (Figure 3) but using 188 cc. of yeast-water instead of 188 cc. of tap water. The

weakening effect of the yeast-water on the gluten was very pronounced (compare Figure 6 with Figure 3).

It must be emphasized here that yeast-water in itself possesses no proteolytic activity. The only acceptable explanation, therefore, of

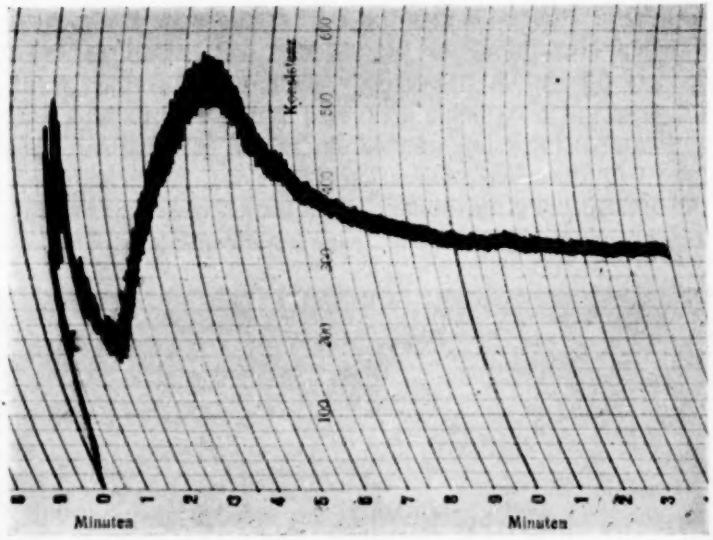

Fig. 6. Farinogram recorded by the same flour as in Figure 3, but using yeast water instead of tap water.

the action of the yeast-water on the gluten must be that the yeast-water activates (stimulates) the proteinases of the flour.

Experiment 5

The stimulating effect which yeast-water exerts on the proteinases of the flour can also be observed when making baking tests.

A baking test was made using the same flour and proceeding in the same manner as in Experiment 3, but using 352 cc. of yeast-water instead of 352 cc. of tap water. In Figure 7 the resulting loaf (marked "YW") has been photographed together with the loaf "W" from Experiment 3, made with tap water. Here, too, the weakening effect of the yeast-water on the gluten clearly appears. The loaf "YW" had a bad crumb and was of small volume. The "measure" of loaf "W" was 42¼ inches whereas the "measure" of loaf "YW" was 39 inches.

In concluding the report of these experiments, it should perhaps be mentioned that further unreported experiments have indicated that the bromate-response of doughs, to which glutathione or yeast-water has been added, is much greater than that of doughs made without

these additions. This is in accordance with the theory of bromate-action referred to above. When bromate acts on the proteinases and the latter are activated by glutathione or yeast-water, then it is obvious that the bromate response must be greater when glutathione or yeast-water is added to the dough.

Further, it should be mentioned that the poor loaf-volumes obtained when glutathione or yeast-water was added to the dough (Experiments 3 and 5, respectively) cannot be ascribed to the gas production of the yeast being depressed by the addition of glutathione or yeast-water. Experiments made by means of the apparatus shown as Figure 1 in an earlier publication (Jørgensen, 1931), have indicated that the quantity of glutathione used in Experiment 3 has no influence on the gas production of the yeast whereas the quantity of yeast-water

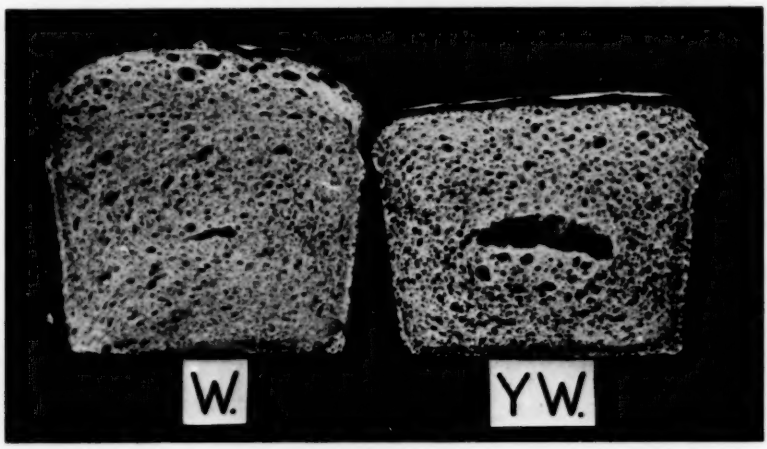

Fig. 7. Loaves made with tap water ("W") and with yeast water ("YW").

used in Experiment 5 has a slight *stimulating* effect on the yeast's gas-production.

Summary

In the present investigation it was shown that wheat flour contains powerful proteolytic enzymes. Usually these enzymes are latent, but activators (glutathione or yeast-water) which in themselves do not possess proteolytic activity, are able to stimulate the proteinases of wheat flour.

After the addition of an activator such as glutathione, the wheat proteinases manifest their presence and strength in a very demonstrative way.

Acknowledgments

The author is indebted to Esther Nielsen, Aa. Andersen and C. Petersen for the valuable assistance given by them while making the investigations described here.

Further thanks are due Prof. S. P. L. Sørensen, President, and Chr. F. Jørgensen, Director of Dansk Gærings-Industri, Ltd., Copenhagen, for their kind permission to publish this paper.

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CORRELATIONS BETWEEN LOAF VOLUME, CRUMB CHARACTERS, BAKING VALUE, AND DIASTATIC ACTIVITY IN CANADIAN WESTERN HARD WHEAT FLOURS

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Trent Institute, Canadian School of Baking, Ontario Agricultural College, Guelph, Ontario, Canada

(Received for publication July 11, 1935)

Introduction

The writer has found in the literature few successful attempts to correlate diastatic activity and baking value or those loaf characteristics that make up the baking value of a flour. It seems possible that more definite information might be obtained on these relationships if, in the baking test, no added sugar were allowed to mask the effects of diastatic action on the finished loaf. Then the only sugars available for gas production in the dough would be those formed as a result of diastasis, and those normally present in the flour. Under these conditions, we might reasonably suppose that the resulting loaf might be more nearly the function of diastatic action.

With this in mind, the author conducted the following tests in an attempt to obtain information on the relationship diastatic activity bears to the baking value, volume, crumb color, and crumb texture of the loaf. The relative gassing power of each flour was also determined and correlated with the diastatic activity (see Figure 1).

Wood (1907) related the diastatic activity of flour to loaf volume. The flour's gassing power has been correlated to diastatic activity by Blish, Sandstedt, and Astleford (1932), Larmour, Geddes, and Whiteside (1933), and Davis and Worley (1934). Sherwood and Bailey (1926) and Grewe and Bailey (1927) claimed that the properly controlled addition of sprouted wheat improved the volume, texture, and crumb color of the loaf. They did not, however, mathematically correlate these loaf characteristics with diastatic activity. Grewe and Bailey (1927) designated a diastatic activity of at least 200 units as being desirable in a good baking flour. That the influence of diastatic activity on the loaf can be controlled by adjusting the quantity of sugar added in the formula was shown by Jørgensen (1931), Swanson (1935), Merritt, Blish, and Sandstedt (1932), and Pascoe, Gortner, and Sher-

wood (1930). According to Treloar, Sherwood, and Bailey (1932) no significant correlation is indicated between crumb color or texture and diastatic activity, although they were able to correlate successfully crumb color and texture.

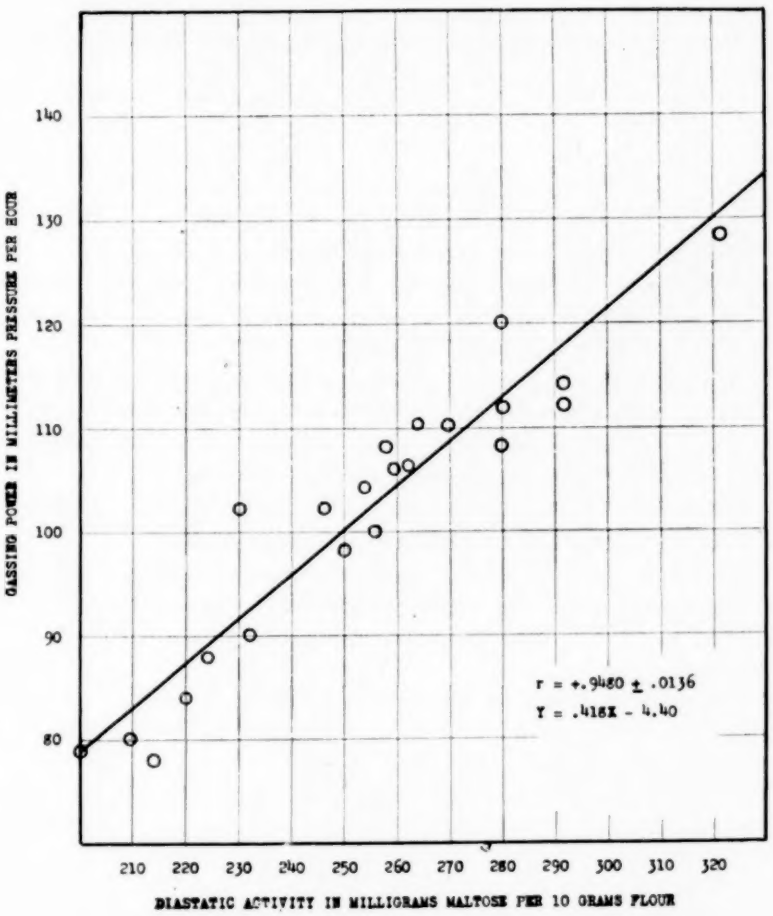

Fig. 1. Relation of "diastatic activity" to "gassing power."

Material

Twenty five second patent and straight run bread flours, received from various Ontario mills, were selected at random. Their ash content range was between 0.43% and 0.51%. The protein content ranged from 12.4% to 14.0%, and the diastatic activity from 210 to 322 units. These samples were collected between June 1, 1934 and March 1, 1935, and represented 2 crop years.

Methods

The diastatic activity was determined by the improved ferricyanide procedure (Blish and Sandstedt, 1933).

The relative gassing power was found by the method of Blish, Sandstedt, and Astleford (1932).

The baking test formula contained no sugar, and is given below:

	Grams
Flour	340
Salt	6
Yeast	11.9
Lard	7
Mineral yeast food	0.85

The ingredients were mixed 4 minutes in a Bachman mixer. The fermentation temperature was 80° F. The dough was punched after 100 minutes, then fermented for an additional 25 minutes before moulding. The proofing period was 60 minutes at 90° F.

At each baking a loaf was baked from a standard flour and used as a basis of comparison for the other loaves. This standard was given a score of 100 for texture, crumb color, volume, and baking value. The scores of all the other loaves were weighed accordingly.

The volume of the loaf was taken 1 hour after baking. A difference of 50 cc. in volume was equivalent to 1 point in scoring.

A crumb color of white, slightly cream, was scored 102 points; white, slightly gray, and cream white—100; cream—98; dull cream, and cream yellow, and cream gray—96; dull cream yellow and dull cream gray—94.

The texture refers to the feel, whether soft, springy, harsh, or soggy; also to the grain of the loaf, which includes the thickness of the cell walls, and size and distribution of cells.

The baking value is the average of the scores for volume, crumb color, and texture.

The Data

The correlations found to exist between the various flour and loaf variables are given in Table I. Significant positive correlations were obtained between diastatic activity and gassing power, diastatic activity and loaf volume, and crumb color and texture.

Significant negative correlations were found between diastatic activity and crumb color, volume and crumb color, protein and volume, and diastatic activity and protein. Smaller negative correlations existed between diastatic activity and texture, volume and texture, and protein and baking value. The correlations between diastatic activity and baking value, protein and texture, and protein and crumb color were negative and very small.

TABLE I

CORRELATION COEFFICIENTS BETWEEN VARIOUS FLOUR AND LOAF VARIABLES

Variables	Coefficient of correlation
Diastatic activity Gassing power	+.9480 ± .0136
Diastatic activity Loaf volume	+.6364 ± .0800
Diastatic activity Texture	−.2146 ± .1287
Diastatic activity Crumb color	−.4203 ± .1110
Diastatic activity Baking value	−.0165 ± .1348
Loaf volume Crumb color	−.3800 ± .1150
Loaf volume Texture	−.1362 ± .1098
Crumb color Texture	+.4767 ± .1042
Protein Loaf volume	−.4274 ± .1102
Diastatic activity Protein	−.3595 ± .1174
Protein Baking value	−.2643 ± .1254
Protein Texture	−.0674 ± .1343
Protein Crumb color	−.0274 ± .1348

TABLE II

PARTIAL CORRELATIONS BETWEEN VARIOUS FLOUR AND LOAF VARIABLES

Variables	Eliminating effect of	Correlation
Diastatic activity Baking value	Protein	−.1238 ± .1328
Diastatic activity Loaf volume	Protein	+.5723 ± .1042
Diastatic activity Texture	Protein	−.2619 ± .1256
Diastatic activity Crumb color	Protein	−.4611 ± .1062
Protein Loaf volume	Diastatic activity	−.2759 ± .1249
Diastatic activity Crumb color	Volume	−.0236 ± .1348
Diastatic activity Texture	Volume	−.1219 ± .1329

A list of partial correlations is given in Table II. The correlations between diastatic activity and baking value, volume, texture, or crumb color are not changed in significance when the protein is held constant. The significant negative correlation between protein and loaf volume becomes insignificant when the effect of diastatic activity is eliminated. When the loaf volume was held constant, the correlation between dia-

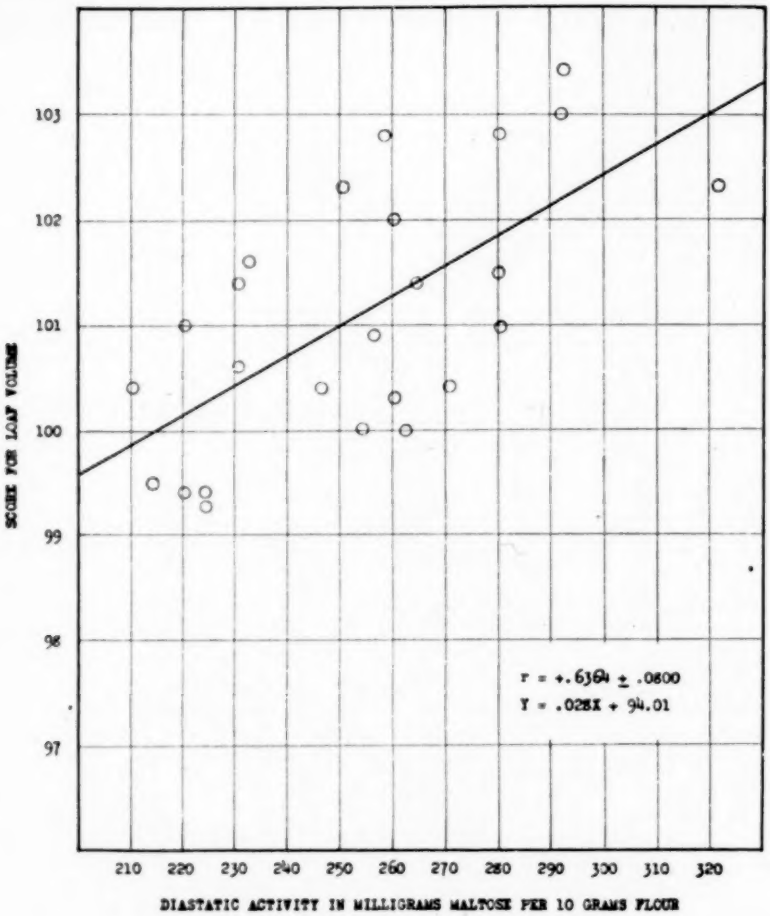

Fig. 2. Relation between "diastatic activity" and loaf volume.

static activity and texture remained insignificant, and between diastatic activity and crumb color the correlation became insignificant.

General Discussion

All the flour samples, dealt with in this research problem, had a greater diastatic activity than 200 units. Evidently none was definitely deficient in diastatic strength.

The close relationship existing between diastatic activity and loaf volume is depicted in Figure 2. Figure 3 illustrates the effect of diastatic activity on the crumb color score.

The correlations between diastatic activity and loaf volume, crumb color, and texture indicate that an increase in diastatic activity raises the

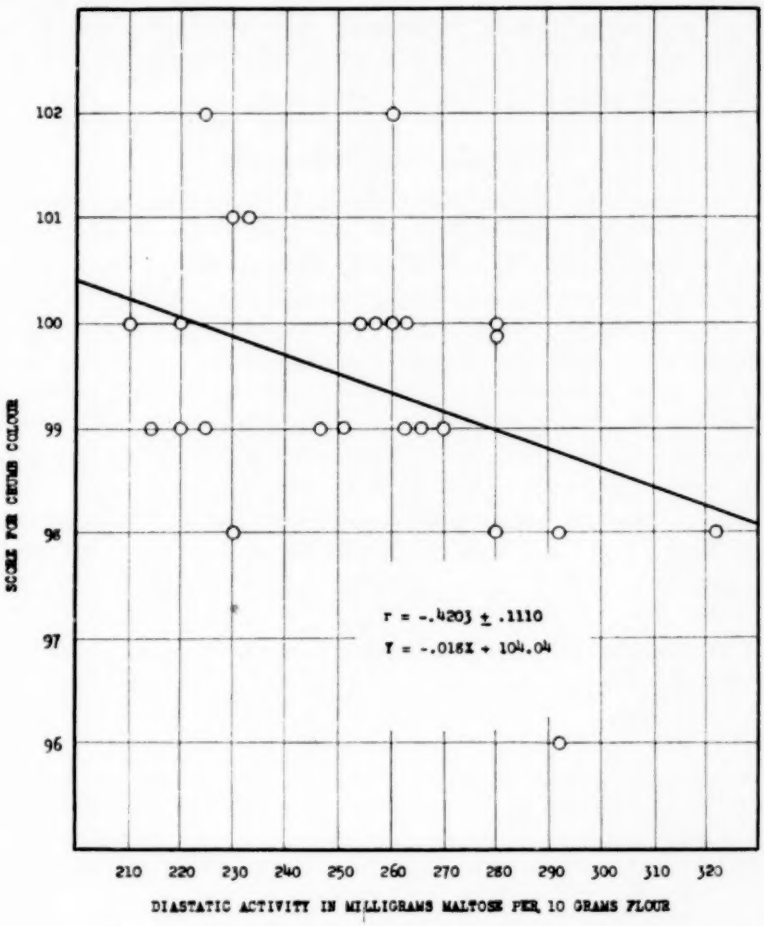

Fig. 3. Relation between "diastatic activity" and crumb colour.

loaf volume score but brings about an almost correspondingly large decrease in the combined crumb color and texture scores. This results in a practically unchanged baking value, and it explains the very small correlation between diastatic activity and baking value.

The partial correlation between diastatic activity and crumb color, eliminating the effect of volume, shows by its lack of significance that diastatic activity is related to crumb color only through the effect of its influence on the loaf volume.

The correlations between protein and the various loaf characteristics, eliminating the effect of diastatic activity, indicate that in the baking test used protein content has but little effect on the test loaves.

The significant correlation between texture and crumb color checks with the results obtained by Treloar, Sherwood, and Bailey (1932). Apparently an improvement in texture would be reflected in an improved crumb color. The relationship between crumb color and loaf volume is inverse. Between texture and loaf volume the relationship is also inverse, though beyond the limits of significance.

Summary and Conclusions

Baking tests without sugar were made on 25 randomly chosen second patent and straight run Canadian Western hard wheat flours with diastatic activity between 210 and 322 units, and correlations found between the variables were as follows: (*a*) significantly positive: diastatic activity and gassing power, diastatic activity and loaf volume, crumb color and texture. (*b*) significantly negative: diastatic activity and crumb color, diastatic activity and protein, loaf volume and crumb color, protein and loaf volume. (*c*) insignificant: diastatic activity and texture, diastatic activity and baking value, loaf volume and texture, protein and baking value, protein and texture, protein and crumb color.

The correlations between diastatic activity and loaf volume, crumb color, and texture compensate one another in such a manner as to make the influence of the diastatic activity variable on the baking value negligible.

The relationship of diastatic activity to crumb color was found to be through the effect of loaf volume.

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ANNUAL REPORT OF TREASURER

M. D. MIZE

January 1, 1936

Since the general form of this report conforms to the style used during past years, a comparison of the financial condition of the Association can be readily obtained by referring to previous reports. The membership of the Association made a healthy growth during the year and increased to within eight of the goal of five hundred members which has been within sight for several years. The arrival at this mark during the coming year should be easily accomplished with the cooperation and interest of every member.

All activities of the Association showed a surplus for the year 1935, with the exception of Experimental Laboratory Baking which has received no income for several years and is being liquidated. The surpluses in most cases were not large which demonstrates a well-planned budget for an association whose objective is to return the maximum value to every member without profit to itself. The surplus shown by CEREAL CHEMISTRY was rather unexpected and due mainly to an increase in advertising, increased number of subscribers, sale of back issues, and reprints.

The printing of Cereal Laboratory Methods was the principal speculative activity undertaken during the year. With the sale of seven hundred and fifty copies within the first year and a surplus of $12.34, it is quite evident that there was a real demand for the new edition and that the price of the book was set at the lowest minimum figure.

DETAILED MEMBERSHIP STATEMENT DECEMBER 31, 1935

	Total	Active	Corp.	Hon.
Membership, Dec. 31, 1934	473	425	46	2
New members added during 1935	46	42	4	0
Members reinstated during 1935	6	6	0	0
Members resigned and suspended for non-payment of dues during 1935	*31*	*26*	*5*	0
Members deceased during 1935	*2*	*2*	0	0
Members in good standing Dec. 31, 1935	492	445	45	2
Net increase in membership during 1935	19	20	*1*	0

PROFIT AND LOSS STATEMENT

January 1 to December 31, 1935

RECEIPTS 1935

Cereal Chemistry			
Membership Dues			
Active		$1,564.50	
Corporation		450.00	
Subscriptions, reprints, back numbers and advertising	$4,929.73		
1935 Accounts Receivable	878.14		
1934 Income received in 1935	*232.10*		
Net 1935		5,575.77	
Interest on Invested Funds		58.75	
Total Net Receipts 1935			$7,649.02
Association			
Membership Dues		1,557.52	
Application Fees		126.00	
Interest on Invested Funds		55.89	
Denver Convention Registration Fees (A)		158.71	
Miscellaneous Income		9.50	
Total Net Receipts 1935			1,907.62
Cereal Laboratory Methods Sales during 1935			1,467.90
Convention Reserve Fund			
Balance of Denver Registration Fees (B)			5.68
Decennial Index			
Received from Cereal Chemistry and Association			162.50
TOTAL RECEIPTS OF ALL ACCOUNTS 1935			$11,192.72

DISBURSEMENTS

Cereal Chemistry				
Cost of printing Journal and Reprints	$4,558.95			
1935 Accounts Payable	1,534.86			
1934 Accounts paid in 1935	*806.34*			
Net 1935		$5,287.47		
Cost of Editing and Miscellaneous Expenses	1,349.40			
1935 Accounts Payable	26.83			
1934 Accounts paid in 1935	*91.02*			
Net 1935		1,285.21		
1934 Accounts Uncollectable		9.92		
Decennial Index—Cereal Chemistry's 1935 Assessment		81.25		
Net Disbursements 1935			$6,663.85	
Surplus 1935				$ 985.17

Association				
Expenses of President's, Vice-President's Office, News Letter		382.01		
Expenses of Secretary-Treasurer's Office		409.03		
Expenses of Secretary's Office since June		33.59		
Committee Expenses		67.71		
Denver Convention Expenses		158.71		
Denver Convention Report	253.70			
Denver Convention Report Accounts Payable	185.00			
		438.70		
History		209.78		
Decennial Index Copies to New Members		48.00		
Decennial Index—Association's 1935 Assessment		81.25		
Miscellaneous Expenses		61.10		
Net Disbursements 1935			1,889.88	
Surplus 1935				17.74
Cereal Laboratory Methods				
Printing, Mailing, Advertising Expenses			1,455.56	
Surplus 1935				12.34
Convention Reserve Fund				
Surplus 1935				5.68
Decennial Index				
Surplus 1935				162.50
Experimental Laboratory Baking Fund				
Printing Reports—Deficit 1935			3.75	
				3.75
TOTAL DISBURSEMENTS OF ALL ACCOUNTS			$10,013.04	

DISTRIBUTION OF NET ASSETS

Cereal Chemistry Assets 1934		$3,097.91	
Surplus 1935		985.17	
Assets Dec. 31, 1935			$4,083.08
Association Assets 1934		3,258.76	
Surplus 1935		17.74	
Assets Dec. 31, 1935			3,276.50
Cereal Laboratory Methods Reserve Fund 1934		462.48	
Surplus 1935		12.34	
Assets Dec. 31, 1935			474.82
Convention Reserve Fund 1934		643.48	
Surplus 1935		5.68	
Assets Dec. 31, 1935			649.16
Decennial Index Fund 1935		*487.50*	
Surplus 1935		162.50	
Deficit Dec. 31, 1935			*325.00*
Experimental Laboratory Baking 1934		84.70	
Deficit 1935		*3.75*	
Assets Dec. 31, 1935			80.95
TOTAL ASSETS DEC. 31, 1935			$8,239.51

FINANCIAL STATEMENT DECEMBER 31, 1935

ASSETS

U. S. National Bank—Checking Account	$ 241.00
Cash on Hand	1,432.58
Petty Cash Fund—Washington, D. C.	200.00
First National Bank—Savings Dept.	1,305.92
Harris Trust Company—Savings Dept.	1,928.56
Building & Loan Stock—Kansas City	2,000.00
U. S. Treasury Bonds	2,000.00
1935 Income Receivable	878.14
GROSS ASSETS	9,986.20
LIABILITIES	
1935 Accounts Payable	*1,746.69*
NET ASSETS	$8,239.51

Note: All amounts in italics are negative amounts and are subtracted from the other amounts in the same column.

REPORTS OF THE AUDITING COMMITTEES

We have examined the books and the report of the Treasurer for the year 1935 and to the best of our knowledge and belief these are a true and accurate account of the receipts and expenditures of the American Association of Cereal Chemists.

H. K. PARKER, *Chairman*
CHAS. GLABAU

We have examined the books of the Managing Editor of CEREAL CHEMISTRY for the calendar year 1935 and find the same to be correct.

B. R. JACOBS, Chairman
L. H. BAILEY
J. A. LECLERC

ERRATA

FURTHER STUDIES ON THE BAKING QUALITY OF FLOUR AS AFFECTED BY CERTAIN ENZYME ACTIONS. Relative Starch Liquefying Power of the Diastatic Agents Investigated, by J. W. READ and L. W. HAAS. Volume XIII, No. 1 (January, 1936).

The numerical values presented in the fourth column of Table III (page 23) should be corrected to read as follows, beginning at top of column:

9,137
6,080
7,625
8,780
6,080
7,025

Some of the calculations which appear in the fifth and sixth columns of Table II (page 22) do not conform exactly to the conditions specified by the empirical equation employed for their evaluation. The data reported in these two columns may be disregarded.